U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-264 936

Water Pollution Caused by Inactive Ore and Mineral Mines - A National Assessment

Toups Corp, Santa Ana, Calif

Prepared for

Industrial Environmental Research Lab -Cincinnati, Ohio Resource Extraction and Handling Div

Dec 76

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-76-298	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE WATER POLLUTION CAUSED BY INACTIVE ORE AND MINERAL MINES - A National Assessment		5. REPORT DATE December 1976 issuing date 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Harry W. Martin William R. Mills, Jr.		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Toups Corporation 1010 N. Main Street Santa Ana, CA 92711		10. PROGRAM ELEMENT NO. 1BB040 11. CONTRACT/GRANT NO. 68-03-2212
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Laboratory - Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE EPA/600/12

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The report identifies the scope and magnitude of water pollution from inactive ore and mineral mines. Data collected from Federal, State, and local agencies indicates water pollution from acids, heavy metals, and sedimentation occurs at over 100 locations and affects over 1200 kilometres of streams and rivers. The metal mining industry was shown to be the principal source of this pollution.

Descriptions of the mineral industry are presented, including a summary of economic geology, production methods, and historic mineral production methods, and historic mineral production. The mechanisms of formation, transporation, and removals of pollutants are detailed.

Annual pollutant loading rates for acid and metals from inactive mines are given and a method provided to determine the extent of mine-related sedimentation in Western watersheds. State-by-state summaries of mine related pollution are presented. An assessment of current water pollution abatement procedures used for inactive mines is given and research and development programs for necessary improvements are recommended.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Water Quality	Ore and Mineral Mines	13/B
Water Pollution	Metal Mining	08/I
Metalliferous Minerals	Acid Mine Drainage	
Metalliferous Mineral Deposits	Heavy Metals	
Mining Waste Disposal	Pollution Control Tech.	
Mine Surveys	R and D Programs	
Assessments		

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 198
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE PC A09-MF A01

EPA Form 2220-1 (9-73)

*USGPO: 1977 — 757-056/5481 Region 5-11

PB 264 936

EPA-600/2-76-298
December 1976

Environmental Protection Technology Series

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/2-76-298
December 1976

WATER POLLUTION CAUSED BY INACTIVE ORE AND MINERAL MINES

A National Assessment

by

Harry W. Martin
William R. Mills, Jr.
Toups Corporation
Santa Ana, California 92711

Contract 68-03-2212

Project Officer

Ronald D. Hill
Resource Extraction and Handling Division
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

ia

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts of our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report describes the first attempt to make a national assessment of the water pollution problems associated with inactive ore and mineral mines. In addition, a review was made of the mining systems that caused these problems, the state-of-art of control methods and research needs. As such, it serves as a basic reference to planning and control agencies formulating state plans and federal agencies mounting an attack on the inactive ore and mineral mine pollution problem. For further information contact the Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

The report identifies the scope and magnitude of water pollution from inactive ore and mineral mines. Data collected from Federal, State, and local agencies indicates water pollution from acids, heavy metals, and sedimentation occurs at over 100 locations and affects over 1,200 kilometres of streams and rivers. The metal mining industry was shown to be the principal source of this pollution.

Descriptions of the mineral industry are presented, including a summary of economic geology, production methods, and historic mineral production. The mechanisms of formation, transportation, and removal of pollutants are detailed.

Annual pollutant loading rates for acid and metals from inactive mines are given and a method provided to determine the extent of mine-related sedimentation in western watersheds. State-by-state summaries of mine related pollution are presented. An assessment of current water pollution abatement procedures used for inactive mines is given and research and development programs for necessary improvements are recommended.

This report was prepared by Toups Corporation, Santa Ana, California in cooperation with Mountain States Research and Development Corporation. It is submitted in fulfillment of Contract No. 68-03-2212 under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period of June, 1975 to August, 1976. Work was completed as of August 15, 1976.

CONTENTS

FOREWORD iii

ABSTRACT iv

FIGURES. viii

TABLES ix

ACKNOWLEDGEMENTS x

SECTION 1. INTRODUCTION 1

PURPOSE. 2

SCOPE. 2
    Conduct of Study. 3
    Limitations of the Study. 3
    Abandoned Versus Inactive Mines 3

IDENTIFICATION OF MINE POLLUTION AREAS 4

SECTION 2. SUMMARY OF CONCLUSIONS 5

SECTION 3. SUMMARY OF RECOMMENDATIONS 7

SECTION 4. THE MINERAL INDUSTRY 8

SCOPE OF THE MINERAL INDUSTRY. 8

ECONOMIC GEOLOGY 8
    Classification of Minerals, Rocks, and Mineral Deposits. 8

PRODUCTION METHODS 9
    Mining. 9
    Mineral Processing. 9
    Processing Technology for Major Commodities 18
    Waste Disposal. 26
    Historical Mineral and Waste Production 27

CONTENTS (continued)

SECTION 5. POLLUTANTS ASSOCIATED WITH MINING 29

FORMATION OF POLLUTANTS 29
  Acid Mine Drainage (AMD) 30
  Heavy Metals 34
  Sedimentation 37

ACID AND METALS IN RECEIVING WATERS 41
  Natural Buffering Systems in Stream Systems 41
  Sulfate as an Indication of AMD 43
  Transportation and Removal of Pollutants in Streams 44

TOXICITIES AND BIOLOGICAL EFFECTS OF POLLUTANTS 56
  Aquatic Life 57
  Municipal and Agricultural Uses 63

SECTION 6. ASSESSMENT OF MINE RELATED WATER POLLUTION 69

DATA COLLECTION PROCEDURE 69

NATIONAL SUMMARY 69
  Regions Exhibiting Major Impact 71
  Methodology of Assessment 73
  Causal Factors Affecting Pollution 84

SECTION 7. ASSESSMENT OF CONTROL TECHNOLOGY FOR INACTIVE MINES . . . 89

EXISTING TECHNOLOGY 89
  Infiltration Control 89
  Retention and Regulation of Mine Drainage 91
  Treatment of AMD 92
  Erosion Prevention 93
  Sedimentation Basins 94

DIFFICULTIES IN IMPLEMENTING CONTROL PROGRAMS 94

SECTION 8. RECOMMENDED RESEARCH AND DEVELOPMENT 96

SPECIFIC PROBLEMS NOT SUFFICIENTLY DOCUMENTED 96
  Effects of Mine Drainage on Groundwater Quality 96
  Assessment of Mercury in Surface Waters from Gold Milling . . . 97

IMPROVEMENT OF POLLUTION MONITORING TECHNIQUES 97
  Monitoring Manual 98

CHEMISTRY RELATED TO MINE DRAINAGE 98

CONTENTS (continued)

PREVENTION TECHNOLOGY 99
  Air Control 99
  Erosion Prevention 101

TREATMENT 102
  Natural Mineral Formations as Traps for Dissolved Ions 102
  Botanical Treatment 103
  Physical Chemical Treatment 103

EFFECTS OF MINING TECHNIQUES ON POLLUTION CONTROL 105

SECTION 9. BIBLIOGRAPHY 106

SECTION 10. APPENDICIES 117

APPENDIX A METRIC CONVERSION 117

APPENDIX B ILLUSTRATION OF VARIOUS MINING TECHNIQUES 118

APPENDIX C HISTORICAL MINERAL PRODUCTION 128

APPENDIX D STATE ASSESSMENT OF PROBLEM AREAS AND POLLUTANT LOADING 144

FIGURES

1 Problem areas 4

2 Typical particle size distribution of ore concentration wastes. 20

3 Pyrite oxidation model. 32

4 Solubilities of oxides and hydroxide of various metals. 36

5 Stability of iron oxides and sulfides 38

6 Stability of iron and copper oxides and sulfides. 39

7 Solubility of calcium sulfate 44

8 Kerber Creek and vicinity 45

9 The pH in Kerber Creek. 47

10 Bicarbonate concentrations in Kerber Creek. 47

11 Hardness concentrations in Kerber Creek 48

12 Total cadmium concentrations in Kerber Creek. 48

13 Dissolved zinc concentrations in Kerber Creek 49

14 Percent of dissolved metals in Kerber Creek 49

15 Gradient of Kerber Creek. 53

16 Effects on typical unit sediment load by tailings 83

17 Average annual runoff in ore and mineral mining areas 88

TABLES

1 Summary of Recommended Research and Development Programs 7

2 Selected, Representative, Metallic and Non-Metallic Minerals. 10

3 Mineralogic and Lithologic Summary of Mineral Deposits 12

4 Classification of Mineral Deposits 16

5 Processing Methods and Reagents Used for Common Metallic Ores 21

6 Classification of Nonmetallics 25

7 Summary of Historical Production of Major Metals and Potential Waste Generated. 28

8 Drainage of the Rawley Mine. 46

9 Comparison of Drinking Water Standards and Effluent Limitations - Selected Drinking Water Standards. 64

10 Empirical Relationship Between Constituents of Mine Drainage 75

11 Summary of Estimated Annual Loading for Metals and Acid. . . . 76

12 Summary of Types of Pollution and Length of Stream Affected. . 85

13 Summary of Sources of Acid and Heavy Metal Pollution 86

14 Summary of Minerals Mined at Problem Areas 87

15 Properties of Kelly Underground Mine Water 92

ACKNOWLEDGEMENTS

The guidance of Ronald Hill, Director of Resource Extraction and Handling Division, Environmental Protection Agency is gratefully acknowledged. We are particularly indebted to the many Federal, State, and local agencies contacted throughout this study for their assistance.

SECTION I

INTRODUCTION

Regardless of the influence of man, mineral deposits are continuously undergoing the natural weathering process of oxidation and erosion. The materials released by weathering slowly find their way into streams, lakes, or groundwaters. This weathering produces acids and metals which result from the oxidation of metallic sulfide ores, principally pyrite. The acid produced accelerates the weathering of many other metallic ores which release heavy metals. This process is a continuing source of nonpoint pollution to the environment.

Mining operations expose vast quantities of previously undisturbed material in the search for valuable minerals. The exposure of these materials in underground workings and tailings provides many potential sources of pollution. Excavation of mine workings frequently intercept groundwater which transports the minerals dissolved by weathering. The groundwater must be either pumped or allowed to freely drain from the workings.

During active mining operations the quantity and quality of flow from an adit may be regulated and the discharge of pollutants controlled. Also water may be diverted around tailings making them less susceptible to erosion and accelerated weathering. When active operations cease, maintenance of control structures may also cease, increasing the possibility of failure and ultimately increased pollution.

Tailings offer another potential source of pollution. Material that is extracted from the ground is crushed and finely ground, greatly increasing the exposed surface area susceptible to weathering. Once a mineral is extracted from the gangue, the non-economic fine material is placed in a tailings pile. Historically, mills were often located near rivers and waste products were either discharged directly into the river or placed in tailings piles. Often these piles were carelessly constructed causing streams to flow through or around them. The exposure of the highly mineralized gangue to water and oxygen causes accelerated weathering and a manifold increase in the discharge in pollutants.

On a national basis, the potential for pollution from these mines is tremendous considering the multitude of abandoned mines and the many potential sources of pollution at each mine. Estimates of the number of abandoned mines in the country vary by orders of magnitude. In an unpublished draft report, the U.S. Bureau of Mines reported 19,000 abandoned and inactive ore and mineral mines and a total of 90,000 mines of all types. This estimate appears quite low. For example, the Bureau reported a total of 3,159 abandoned and inactive mines in California but the California State Department of Geology estimates the number to be in excess of 30,000. In North Carolina, the Bureau reported only 78 abandoned and inactive metal mines, but the State Department of Natural and Economic Resources estimates the number of abandoned gold mines alone to exceed 700. From these examples, it appears that the number of abandoned and inactive ore and mineral mines is far in excess of the 19,000 reported by the Bureau and may well be on the order of magnitude of ten times of the reported numbers.

PURPOSE

The discharge of mineralized acidic waters from inactive mines has overloaded the assimilative capacities of many receiving waters creating a distressed environment. To date, no comprehensive assessment has been conducted to determine the extent of this type of pollution. In addition, the extent of utilization of pollution control procedures at inactive mines is not known.

The purposes of this study have been to:

- Identify the nature and extent of water pollution caused by inactive ore and mineral mines. Pollution problems associated with mining of coal, natural gas, petroleum, and sand and gravel are not included.
- Determine present water pollution abatement technology available for inactive mines.
- Determine use and effectiveness of pollution abatement technology.
- Prepare research and development programs for development of technology to adequately control water pollution caused by inactive mines.

SCOPE

This study considered water pollution from inactive ore and mineral mines throughout the United States. Water pollution problems caused by pollutants discharged during active mining operations were excluded as the discharge has ceased and often is not attributable to a specific source. For example, high mercury concentrations have been measured in stream sediments below old gold milling operations that used mercury for amalgamation. This is a result of allowing mercury to escape during active mining. Once the mill closed, the discharge ceased but the pollution continued. These types of problems were not investigated in the course of this study but may well be a suitable topic for further study.

CONDUCT OF STUDY

Due to the size of the study area and the vast number of abandoned mines, the study was limited to collecting data on known pollution problems. Project team personnel were not directed to perform any site visits.

This study was conducted in the 12-month period between July 1975 and July 1976. Since many Federal, State and Local Agencies are cognizant of pollution problems from inactive mines, it was necessary to contact several hundred offices of various agencies to perform the assessment phase of this study. Each State Water Pollution Control Office was contacted to determine their knowledge of inactive mine pollution and data available. Where a significant problem in mine prelated pollution occurred, members of the study team visited the agencies to review their files. To augment this data, regional offices of the following Federal Agencies were contacted:

> U.S. Bureau of Land Mangement, U.S. Bureau of Mines, U.S. Environmental Protection Agency, U.S. Forest and Wildlife Service, U.S. Forestry Service, U.S. Geological Survey, and U.S. National Park Service.

Many of the directors of these agencies referred the requests for information to their subordinant local offices, which frequently responded with detailed data that complimented the data collected from the State Agencies.

LIMITATIONS OF THE STUDY

The study presents a summary of data collected from these various sources. It is recognized that many of the states have concentrated their pollution control efforts toward identifying point source pollution problems and have not had the budget or manpower to perform a detailed analysis of non-point source pollution problems such as those associated with abandoned mines. This study is, therefore, limited in detail to the level of analysis performed in each state. This study should be used as a broad-based planning guide and should not be interpreted as an assessment with a sufficient level of detail for use on a localized basis.

ABANDONED VERSUS INACTIVE MINES

Frequently the term abandoned is used to identify a mine not currently being operated. However, the common and legal terminology may cause confusion. Often mines are temporarily inactive due to adverse economic conditions and may reopen if economic conditions change. Abandonment in its legal sense is related to ownership. For a mine to be abandoned, there must be a relinquishment of rights with the intent never to return. This is rarely the case in non-fuel mines. For the purposes of this study, the term "inactive" will refer to mines not currently being worked. Inactive portions of active operations will be excluded as there is often no clear demarcation between the active and inactive site.

IDENTIFICATION OF MINE POLLUTION AREAS

A majority of data collected during the course of the study identified specific problem areas or reaches of streams and river polluted by mine drainage. The agencies reporting the data often treated these problem areas as a single unit and had not yet performed an analysis of sufficient detail to identify each discrete polluted discharge affecting the stream. When many mines were involved, their specific numbers was often unknown. However, since a mineral mine may be a single adit driven a short distance in search for ore or may be a large complex containing many audits, haulageways and mined out slopes covering thousands of square feet, the number of mines is not as important as the number of discharges.

Areas of water pollution caused by mining are referred to as problem areas. A plot of these areas is shown on Figure 1. The areas are identified by a two-letter state abbreviation followed by an identification number.

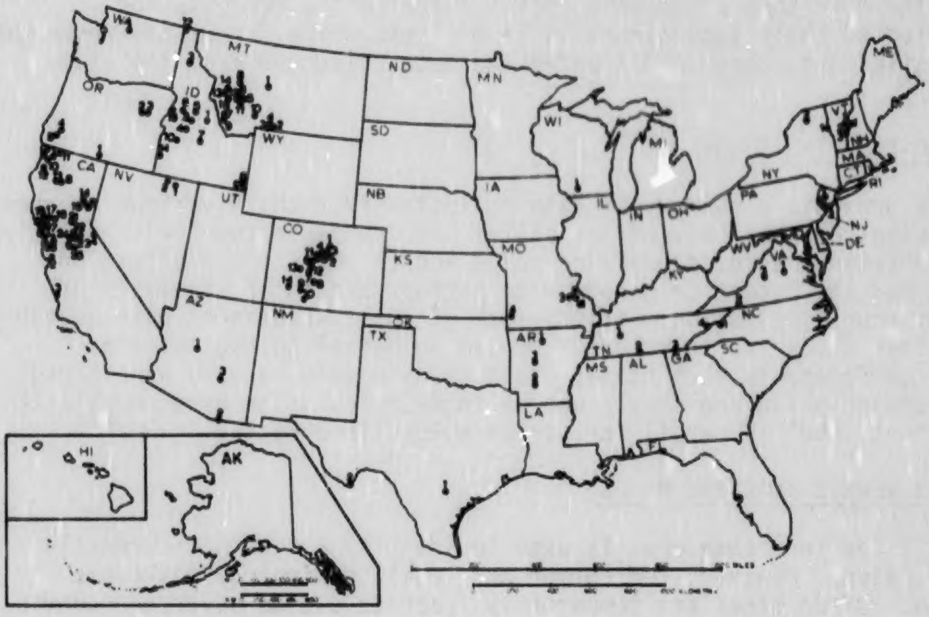

WA
MT
OR
ID
ND
MN
ME
WI
SD
WY
MI
VT
NH
MA
CA
NV
UT
CT
RI
NY
IA
NB
PA
IL
IN
OH
NJ
DE
CO
KS
MO
WV
VA
KY
AZ
NM
OK
TX
AR
NC
TN
SC
MS
AL
GA
LA
FL
HI
AK

Figure 1. Problem areas.

SECTION 2

SUMMARY OF CONCLUSIONS

The following conclusions have been made based on the findings of this study:

1. More than 1,200 kilometres of streams and rivers at over 100 locations have been adversely affected by past mining activities.

2. In excess of 30,000 metric tons of acid and 10,000 metric tons of heavy metals are being discharged annually into the nation's surface waters. This does not account for discharges from mines which are not causing water quality problems but which may be the source of low level non-point source pollution.

3. The metal mining industry contributes the majority of this pollution. The principal mining activities involved are: gold, copper, silver, lead, zinc, and mercury in descending order of importance.

4. The metal mining industry has produced in excess of 30 billion metric tons of tailings and waste material.

5. Acid mine drainage, heavy metals, and sedimentation are the principal pollutants.

6. On a statewide basis, water pollution from inactive mines is usually not assigned a high priority in relationship to the total pollution problems in the state, however, on a localized basis it can be a severe problem.

7. Approximately 70 percent of the polluted streams are affected by acid and metals; 30 percent are affected by sediment.

8. Acid and metals may be released from tailings, adits, or pits. The study results indicate that the source of pollution is from tailings greater than 50 percent of the time, adits of underground mines greater than 30 percent, and open pit/mines less than 10 percent.

9. No correlation could be determined between average annual runoff and pollutant loading. However, the majority of pollution problems occur in areas where the average annual runoff exceeds 2.5 centimetres.

10. The discharge of pollutants is a function of many factors such as climate, mineralogic and lithologic characteristics of the host ore

body, volume of material disturbed during mining activities, and amount of water flowing through mine workings or tailings.

11. The metallic pollutants associated with mine drainage precipitate and settle to the bottom of streams and lakes. These metals may be redissolved by chemical or biological mechanisms and re-enter the aquatic ecosystem for many years after the discharge has ceased. An example of this is the methylation of elemental mercury.

12. In most states, adequate data is not available on the inactive mine problem, including number of situations, actual number of mines and polluting discharges, source of pollution, characteristics of pollution and length of stream degraded.

13. No adequate model presently exists to predict annual pollutant loading from inactive metal mines or mining areas.

14. The erosion of tailings may have a severe impact on a watershed and is dependent on many factors including local soil conditions, climate and terrain, size of watershed, type of tailings, and area of watershed covered by tailings. These many variables make it impractical to predict sediment produced by inactive mines on a national basis.

15. Groundwaters are a substantial component of the water resources of the country. The impact of mine drainage from inactive mines may be severe but the effects are unknown due to the lack of groundwater quality monitoring programs at inactive mine sites.

16. Reclamation of tailings and water diversion are the only technologies currently used for pollution abatement.

17. Thorough assessment of water pollution caused by inactive mines is often incomplete and has received a low priority status in many areas. The states are reluctant to budget funds on problem identification because the implementation of pollution abatement programs is often stagnated by factors such as: different ownership of surface and mineral rights causing questions of responsibility, inadequate abatement technology, possibility of reopening claims, cost effectiveness, and lack of funding.

SECTION 3

SUMMARY OF RECOMMENDATIONS

The results of this study have indicated that research and development programs are necessary to solve water pollution from inactive ore and mineral mines. These programs are fully developed in Section 8 and are outlined in Table 1.

TABLE 1. SUMMARY OF RECOMMENDED RESEARCH AND DEVELOPMENT PROGRAMS [a]

Program	Research	Development	Demonstration
Specific Problems not Documented			
Groundwater Pollution	●		
Effects of Mercury from Gold Mining	●		
Improvement of Pollution Monitoring Techniques			
Monitoring Manual	●	●	
Instrumentation	●	●	
Chemistry of Mine Drainage	●		
Prevention Technology			
Air Control			
Air Seals			●
Provision of an inert atmosphere	●	●	○
Mine Flooding			●
Erosion Prevention	●	●	●
Treatment			
Natural Formation as Traps	●	●	○
Botanical	●	●	○
Physical-Chemical			
Precipitation	●	●	●
Foam Flotation	●	●	●
Reverse Osmosis	●	●	○
Mining Techniques			
Mining Methods	●	●	
Mine Shutdown Manual	●	●	

[a] ● Recommended program.
○ Recommended program pending suitable results of prior program.

SECTION 4

THE MINERAL INDUSTRY

This section will give a brief introduction into mineral industry. An overview of economic geology is presented to familiarize the reader with the minerals and compounds that may be a source of pollution. Production methods are then described with emphasis on the potential pollutants, waste disposal and tailings placement. Finally, historical metal production is summarized for all states.

SCOPE OF THE MINERAL INDUSTRY

The mineral industry includes the discovery and exploitation of useful elements, minerals, and rocks which occur in the Earth's crust. Discovery involves application of earth sciences disciplines such as economic geology, geochemistry and geophysics; exploitation follows discovery through the practical use of mining engineering, mining geology, metallurgical engineering, and mineral economics.

The majority of water pollution in the mineral industry is the result of the oxidation of base metal sulfide compounds. Pyrites (iron sulfides) are present in practically all metallic mineral deposits, many nonmetallic deposits (as a secondary constituent of major rock formations), and other diverse geologic environments. Other metallic sulfides (ore minerals) are also sources of pollution, accented by toxicity of many essential, varietal, and associated trace elements. Since the sulfide metals are the predominent source of pollution, specific emphasis will be placed in this section on the processing and production of the major sulfide metals which are copper, lead, mercury, molybdenum, nickel, silver, and zinc.

ECONOMIC GEOLOGY

Economic geology is the one subdiscipline of geological science directly concerned with the mineral industry. An understanding of the basics of this discipline is desirable to comprehend the significance of the industry and assess its impact on environment.

CLASSIFICATION OF MINERALS, ROCKS, AND MINERAL DEPOSITS

Mineral matter may be considered as the building blocks of rock. Minerals are composed of chemical substances -- bound together and exhibiting crystal forms dictated by natural physical and chemical laws. Pertinent details in the categories of the two major divisions of minerals, metallic and non-metallic, are outlined in Table 2. All rocks are classified under three major categories or types, according to their origin: igneous, sedimentary, and metamorphic.

Ores (or ore deposits) can be defined simply as natural assemblages and mixtures of minerals and rocks that can be mined for profit. Thus, most commercial deposits contain two essential items: the ore mineral (or rock) of value; and the associated worthless minerals or rock materials (gangue).

Rock material enveloping an ore deposit is known as the host or country rock. The latter term is used primarily in underground mining. In surface mining operations, the soil and/or rocks which overlie the ore deposit are overburden. A summary of the minerals and rock materials, the overburden, host rock, ore and gangue are shown for various mineral deposits in Table 3.

An understanding of the varied forms of mineral deposit occurrence can be helpful in assessing the location and type of water pollution to be expected from inactive mineral industry operations. An outline classification of mineral deposits is shown in Table 4. The table has been arranged using the major headings of: "Syngenetic" (formed at the same time as the enclosing rock); and "Epigenetic" (those formed in preexisting rock). Few of the nonmetallic minerals are included in this classification.

PRODUCTION METHODS

Production practices of the mineral industry fall under the major headings of mining and processing (beneficiation). Details of these complex technologies are briefly discussed and illustrated herein, and waste disposal techniques summarized.

MINING

All general mining practices are classified under the two categories of surface and underground. A third category, marine technology in ocean mining, is developing rapidly and is currently in the experimental stage. It is therefore not included in this report.

Surface Mining

Surface mining techniques are applied to deposits at or near the surface of the ground, including placer and open cut mining. Placers denote transported deposits of heavy minerals which have accumulated through natural processes of weathering, erosion, and gravity concentration. Deposition is normally accomplished through the action of running water.

Placer mining operations range in size from a single prospector, panning gold and sluicing, through the larger developments involving high-pressure washing techniques (hydraulicing) and dredging.

TABLE 2. SELECTED, REPRESENTATIVE, METALLIC AND NON-METALLIC MINERALS

METALLIC

CLASS (Useful Substance)	MINERAL NAMES	CHEMICAL COMPOSITION		
		Formula(e)	Similar Varieties	Trace Minerals
CARBONATES				
Copper	Azurite	$2\ CuCO_3.Cu(OH)_2$	Malachite	Fe(Iron)
Lead	Cerussite	$PbCO_3$		Zn(Zinc)
Manganese	Rhodochrosite	$MnCO_3$		Fe(Iron)
Zinc	Smithsonite	$ZnCO_3$	Hydrozincite	Mn(Manganese)
HALIDES				
Silver	Cerargyrite	$AgCl$	Embolite	Hg(Mercury)
NATIVE ELEMENTS	Copper (Cu)			
	Gold (Au)			
	Silver (Ag)			
OXIDES				
Aluminum	Gibbsite (Bauxite)	$Al_2O_3.2H_2O$	Diaspore	Fe(Iron)
Chromium	Chromite	$FeCr_2O_4$		Mg(Magnesium)
Copper	Cuprite	Cu_2O	Tenorite	Fe(Iron)
Iron	Hematite	Fe_2O_3	Limonite	Mn(Manganese)
	Magnetite	Fe_3O_4		
Manganese	Pyrolusite	MnO_2	Psilomelane	Ba(Barium)
Titanium	Rutile	TiO_2	Ilmenite	Fe(Iron)
Uranium	Uraninite	Complex	(Vanadates)	Ra;Th;Pb
SILICATES				
Nickel	Garnierite	$(Ni,Mg)SiO_3.nH_2O$		
Zinc	Hemimorphite	H_2ZnSiO_5		Al(Aluminimum)
TELLURIDES				
Gold	Calaverite	$AuTe_2$		Ag(Silver)
Silver	Sylvanite	$(Au, Ag)Te_2$		
TUNSTATES	Wolframite	$(Fe, Mn)\ WO_4$	Scheelite	Mo(Molybdenum)
SULFIDES				
Copper	Bornite	$Cu_5Fe\ S_4$		
	Chalcocite	Cu_2S	Covellite	
	Chalcopyrite	$CuFe\ S_2$	Pyrite	
Lead	Galena	PbS		Ag(Silver)
Mercury	Cinnabar	HgS		Fe(Iron)
Molybdenum	Molybdenite	MoS_2		
Nickel	Pentlandite	$(Fe, Ni)S$		Co(Cobalt
Silver	Argentite	Ag_2S		Pb(Lead)
Zinc	Sphalerite	ZnS		Cd(Cadmium)

(Continued)

TABLE 2. SELECTED, REPRESENTATIVE, METALLIC AND NON-METALLIC MINERALS (Continued)

METALLIC

CLASS (Useful Substance)	MINERAL OR ROCK NAMES	CHEMICAL COMPOSITION		
		Formula(e)	Similar Varieties	Trace Minerals
CARBONATES				
Dolomite	Dolomite	$CaMg(CO_3)_2$		Fe (Iron)
Limestone	Calcite	$CaCO_3$		Mn (Manganese)
Magnesium	Magnesite	$MgCO_3$		Ca (Calcium)
HALIDES				
Salt	Halite	$NaCl$		Mg (Magnesium)
Fluorine	Fluorite	CaF_2		Ba (Barium)
HYDROXIDES				
Boron	Borax	$Na_2B_4O_7.10H_2O$		Ca (Calcium)
Magnesium	Brucite	$Mg(OH)_2$		Fe; Ca
NATIVE ELEMENTS	Carbon (C)			
	Sulfur (S)			
PHOSPHATES				
Lithium	Amblygonite	$LiAl(F,OH)\ PO_4$		Na (Solium)
Phosphorus	Phosphorite	$Ca_3(PO_4)2.H_2O$	Apatite	(Radioactive)
POTASH SALTS				
Potassium	Sylvite	KCl	Halite	Na (Solium)
SILICATES				
Bentonite	Montmorillonite	(Complex) Caly Mineral (Group)		Li (Lithium)
Asbestos	Chrysotile	$Mg_3Si_2O_5(OH)_4$		Ni (Nickel)
Potash	Orthoclase	$KAlSi_3O_8$	Microcline	Na (Sodium)
Garnet	(Complex Mineral Group)			Mg; Mn
Kaolin	Kaolinite	$Al_2Si_2O_5(OH)_4$		
Refractories	Kyanite	Al_2SiO_5		
Micas	(Complex Mineral Group)			Li (Lithium)
Alumina	Nepheline	$(Na,K)\ (Al,\ Si_2O_4$		
Rdfractories	Olivine	$(Mf,\ Fe_2SiO_4$	Sepentine	Cr (Chromium)
Silicas	Quartz	SiO_2	Opal	
Lithium	Spodumene	$LiAlSi_2O_6$		Na (Sodium)
Talc	Steatite	$Mg_3Si_2O_5(OH)_4$		
SULFATES				
Aluminum	Alunite	$KAl_3(OH)_6SO_4)_2$	Jarosite	Sodium
Barium	Barite	$BaSO_4$		Sr (Strontium)
Calcium	Gypsum	$CaSO_4.2H_2O$	Anhydrite	Mg; Na; Cl
SULFIDES				
Sulfur	Pyrite	FeS_2	Pyrrhotite	Au (Gold)

TABLE 3 MINERALOGIC AND LITHOLOGIC SUMMARY OF MINERAL DEPOSITS

Deposit	Rock Type(s)	Mineral(s) and/or Rock Material(s) of:			
		Overburden [a]	Host Rock	Ore	Gangue
Aluminum	Igneous (residual)	Clays, soil	Syenite	Bauxite	Aluminum, silicates
Antimony	Igneous & Sedimentary		Quartz veins	Stibnite	Quartz, sulfides
Arsenic	Igneous & Sedimentary		Quartz veins	Arsenic	quartz, sulfides
Asbestos	Metamorphic		Serpentine	Chrysotile	Magnesian, silicates
Barium	Sedimentary	Clays, soil	Carbonates, shales	Barite	Calcite, quartz, fluorite
Bentonite	Igneous	Shale, sandstone, clay	Montmorillonitic clay	Montmorillonite (clay)	Impure clay
Bismuth	Igneous & Sedimentary		Monzonites, carbonates	Bismuth	(See lead, tin, deposits)
Borate	Sedimentary	Clays, soil, alluvium	Evaporites (salts)	Borax	Impure borates
Cadmium	Sedimentary		(with zinc minerals)	Greenockite	
Chromium	Igneous & Metamorphic		Peridotites	Chromite	Olivine, corundum
Cobalt	Metamorphic		Metamorphic	Cobaltite	
Copper	Igneous & Sedimentary	Soil, host rocks and related types	Granitic rocks, sandstone and limestone	Azurite Bornite Chalcocite Chalcopyrite Covellite Energite Malachite	Host rock and minerals (limestone diorites, monzonites, sandstone, etc.)
Diatomite	Sedimentary	Clays, soil	Monomineralic	Opal	Clays, sands, etc.
Dolomite	Sedimentary	Host rocks and related types			
Fluorspar	Sedimentary	Common sediments	Calcite, dolomite	Fluorite	Host rock, barite
Garnet	Metamorphic	Silicates	Silicates	Complex silicates	Silicates
Gold	Igneous & Sedimentary		Quartz, volcanics	Calaverite Native Gold (Au) Sylvanite	Silica, pyrite
Graphite	Metamorphic	Host rocks, soil	Schist, gneiss	Carbon	Host rock, silicates
Gypsum	Sedimentary	Host rocks, soil	Shales, clays	Gypsum	Anhydrite
Iron	Sedimentary, Igneous & Metamorphic	Host rocks, soil	Shales, limestone sandstones, gneiss, gabbro	Hematite Siderite	Host rocks, sulfides

(Continued)

TABLE 3. MINERALOGIC AND LITHOLOGIC SUMMARY OF MINERAL DEPOSITS (continued)

Deposit	Rock Type(s)	Mineral(s) and/or Rock Materials(s) of:			
		Overburden [a]	Host Rock	Ore	Gangue
Kaolin	Igneous (residual and Sedimentary	Host rocks, soil	Granite (residium) and common clays	Kaolinite	Silicates, impure clays, iron oxide
Lead	Sedimentary, Metamorphic and Igneous		Carbonates, shales quartzites, slates	Anglesite Cerussite Galena	Barite, fluorite sulfides, oxides
Limestone	Sedimentary	Soils, host rocks, and related types		Limestone	Impure limestone, iron oxide
Magnesium	Sedimentary	Host rocks, soil	Dolomite	Carnallite	Impure host rock minerals
Manganese	Igneous, Sedimentary and Metamorphic	Host rocks, soil	Clays, limestone, schist	Braunite Manganite Psilomelane Pyrolusite Rhodochrosite	
Mercury	Metamorphic & Sedimentary		Slate, quartzite, limestone	Cinnabar	Quartz, opal, pyrite
Molybdenum	Igneous		Granite, monzonite	Molybdenite Wulfenite	Fluorite, sulfides, iron oxides
Nepheline Syenite	Igneous	Impure host rock, soil	Monomineralic	Nepheline Syenite	Biotite, hornblende
Nickel	Igneous		Quartz, diorite, norite greenstones	Pentlandite Garnierite	Pyrrhotite, silicates, oxides
Olivine	Metamorphic	Impure host rock, soil	Dunite	Forsterite Fayalite	Iron and magnesian silicates
Pegmatite	Igneous & Metamorphic	Mixed host rock, soil	Granite, schist	Beryl Feldspar Lithium minerals Micas Quartz Rare earths	Host rock, impurities biotite, hornblende, iron oxides

(Continued)

TABLE 3. MINERALOGIC AND LITHOLOGIC SUMMARY OF MINERAL DEPOSITS (continued)

Deposit	Rock Type(s)	Mineral(s) and/or Rock Materials(s) of:			
		Overburden [a]	Host Rock	Ore	Gangue
Phosphate	Igneous & Sedimentary	Clays, sands, soil	Phosphorite, guano, apatites	Apatite Colophonite	Limes, silica, iron oxides, uranium oxides, clays
Platinum	Igneous & Sedimentary		Pyroxenites, dunites	Native platinum	Ferro-magnesian silicates
Potash	Sedimentary (evaporites)		Shales, clays	Sylvite	Impure evaporites
Quartz	Igneous & Sedimentary	Clays, soil	Granitic rocks, alluvium	Quartz	Iron oxides, calcite, clays
Rock Salt	Sedimentary	Host rocks and related types	Common sediments	Halite	Impure salts, anhydrite, gypsum
Silver	Igneous & Sedimentary		Quartz, quartzite, volcanics	Argentite Cerargyrite Native Silver Proustite	Quartz, barite, manganese oxides, and base metal sulfides
Stone (Dimension)	Igneous, Metamorphic and Sedimentary	Impure host rock	Granite, marble conglomerate, sandstone	Granites Marbles Serpentine	Impure host rock
Strontium	Igneous & Sedimentary		Marls, dolomite	Strontianite	Sulfur, gypsum
Sulfur	Igneous & Sedimentary		Common sediments, volcanics	Native Sulfur Pyrite	Salts, anhydrite, sulfides, etc.
Talc	Metamorphic		Altered limestone, serpentine, gneiss schist, slate	(Steatite) (Soapstone-fine crystalline)	Silicates
Thorium	Igneous & Sedimentary		Granite, sandstone	Thorianite	Silicz, impure host
Tin	Igneous & Sedimentary		Granite alluvium	Cassiterite	Granite, quartz
Titanium	Igneous & Sedimentary		Syenite, alluvium beach sands	Ilmenite Rutile	Iron oxides, impure host rocks

(Continued)

TABLE 3. MINERALOGIC AND LITHOLOGIC SUMMARY OF MINERAL DEPOSITS (continued)

Deposit	Rock Type(s)	Mineral(s) and/or Rock Materials(s) of:			
		Overburden [a]	Host Rock	Ore	Gangue
Tungsten	Igneous & Sedimentary		Granite alluvium residium	Scheelite Wolframite	Quartz, fluorite, micas
Uranium	Igneous & Sedimentary	Barren host rock	Granite, phosphate rock shales, sandstones	Carnotite Uraninite (complex oxide)	Impure host rocks Quartz, carbonates
Vanadium	Sedimentary	Barren host rock	Shales, limestone Phosphate rock sandstones	Patronite (complex) Carnotite (vanadate) Roscoelite (mica)	Mica, impure host rock, rare V minerals
Zinc	Sedimentary, Igneous		Carbonates, granitic rocks, quartzites, slates	Sphalerite Smithsonite Hemimorphite	Pyrite, fluorite, Barite, impure host rock

TABLE 4. CLASSIFICATION OF MINERAL DEPOSITS

Process	Examples of Deposits	
	Commodity(ies)	Location
SYNGENETIC		
Igneous Concentration		
Disseminated	Diamonds	South Africa
Segregated	Chromium	South Africa
Injected	Magnetite	Sweden
Sublimation	Sulphur	Gulf Coast of U.S.
Sedimentation		
Chemical	Iron (Hematite)	Appalachian Area
	Manganese	Tennessee
	Phosphate rock	Florida
Contact Metamorphic	Iron (Magnetite)	Cornwall, England
	Copper	Morenci, Arizona
	Gold	Worldwide
Metamorphic	Graphite	Alabama
	Asbestos	Maine
	Talc	North Carolina
	Sillimanite Group	North Carolina
	Garnet	New York
EPIGENETIC		
Cavity Filling		
Fissure Veins	Mercury	California
Shear Zones	Gold	New Zealand
Breccias	Zinc	East Tennessee
Solution Openings	Lead & Zinc	Wisconsin
Pore Spaces	Copper (Red Beds)	New Mexico
Vesicular	Copper	Lake Superior Area
Replacement		
Massive	Copper	Bisbee, Arizona
Disseminated	Porphyry Coppers	Western U.S.
Concentration		
Residual	Iron	Lake Superior Area
	Manganese	Gold Coast (Africa)
	Bauxite	Arkansas
Mechanical	Gold (Placer)	California
	Tin (Placer)	Dutch East Indies
Enrichment	Copper	Ray, Arizona
Evaporation	Gypsum, Salts	Western U.S.
Metamorphosed	Lead	Coeur d'Alene, Idaho

Open cut mining methods apply to the surface or shallow deposits which are "in place", i.e., have not been transported. Typical open cut mining operations include the following:

- Open Pits - developed by benches
- Strip Mines - developed by long, usually shallow, cuts
- Quarries - usually developed in massive rock formations with prominent topographic expression (cliffs, etc.)

Underground Mining

Underground mining techniques have evolved from simple tunnels driven horizontally in rock to the complex development now represented by the great mines of the world. Mining plans for a given deposit are drawn on the basis of its geometry and position relative to the ground surface. Important considerations are the choice of vertical or inclined shafts, and adits (tunnels) for access and haulageways. The techniques and practices of underground mining are outlined below. Illustrations of various mining techniques are shown in Appendix B.

1. Open Stopes (excavations from which ore has been mined)

    A. Sublevel stoping - withdrawal of ore on a haulage level below the ore.

    B. Shrinkage stoping - broken ore is left temporarily as a working platform in the stope, and the ore is mined upward.

    C. Glory holes - a funnel shaped excavation, the bottom of which is connected by an opening to a lower haulage level, and the top of which is open to the sky.

2. Supported Stopes

    A. Natural pillars - columns of undisturbed ore are left to support the roof (or back) of stopes.

    B. Artificial support - (Timber posts, stulls, cribs, reinforced concrete)

        a. Cut-and fill stoping - after ore is removed, waste rock is brought in and mining continued - using the waste as a base.

        b. Square-set stoping - used for unstable rock (heavy ground) that requires immediate support. Square-sets are built of heavy timbers.

3. Caving Methods

    A. Top Slicing - ore is removed in a series of horizontal slices, beginning at the top.

B. Sublevel caving - mining every other slice by driving crosscuts (level access openings). The ore between the crosscuts, as well as that above, is then mined.

C. Block caving - undercutting large blocks of ore and removing the broken rock through haulageways underneath.

4. Flat Seam

A. Room and pillar - roof supported by pillars of undisturbed ore.

B. Checkerboard - variation of room and pillar method.

C. Longwall - mining is advanced over a long front; mined out areas at the rear are allowed to cave.

D. Augering - mining by augering machine.

5. Solution Mining

A. Frasch Process - pumping hot water down through a concentric arrangement of vertical openings to melt the desired material which is then pumped to the surface in liquid form.

B. Leaching of metallic ores in-situ - leaching fragmented and unfragmented ores in place by application of leaching solution, and return of solution to a surface plant for recovery of metal values.

C. Solution of soluble salts - similar in operation to the Frasch Process.

D. Borehole mining - injection of leaching solution into an orebody through a borehole and recovery of the solution through peripheral boreholes.

MINERAL PROCESSING

The second major step in mineral industry production is processing. Except for a few mineral and rock commodities, practically all ores require some degree of metallurgical beneficiation in order to produce a marketable product. Processing techniques are classified under the main headings of sizing, sorting, concentrating and metallurgical processing.

Sizing

Depending on the end product, crude material is crushed and/or ground to specifications dictated by either the market or further processing requirements. Coarser size ranges result from sizing the crude materials in either one or a series of crushers which are designed to reduce the rock to sizes required for the next step. The grinding stage, if necessary, is simply an extension of the crushing process. It is designed to gain a further reduction in size.

Sorting

Additional beneficiation may be required to separate valuable materials from those of no value. For convenience and clarity, all processes in this category, from a simple manual separation (hand sorting) to the sophisticated chemical and metallurgical techniques of flotation, are grouped under the general heading of sorting. Washing is removing unwanted materials such as clays, muds, and soils. Magnetic separation is the utilization of inherent magnetic properties in either the ore mineral or gangue for separation. Concentration has the greatest interest for this study since it is this process that generates the solid waste or tailings. It will be discussed in greater detail.

Concentration

Gravity concentration is a method of separating grains of minerals of different densities. It is usually applied where the waste rock has a low density (2.5 to 3.0) and the valuable mineral has a high density (4.0 to 7.5). Gravity concentration was used from the late 1800's to the 1920's when froth flotation replaced many of the gravity concentration applications.

Froth flotation is a chemically induced method for beneficiating or upgrading an ore, which utilizes a layer or column of froth as a separating medium to segregate and remove the valuable minerals from the worthless gangue components of a finely ground ore suspended in water.

No metallurgical process developed in the 20th century compares with froth flotation in its effect on the mineral industry. Processes like gravity concentration, amalgamation, and pyrometallurgical reduction are of ancient origin; others like cyanidation and electrolytic reduction were well established by 1900. Although metallurgical processes such as heavy-media separation, ion-exchange, and solvent extraction are new, their influence is small compared with froth flotation.

The purpose of grinding ore material is to expose the valuable minerals. The finer the grind, the higher the probability of an ore particle being released from the gangue material. However, grinding adds to the cost of production and in a gravity separation process very fine material will not segregate properly. The particle sizes of the ground ore material were changed during the transition period from gravity separation to froth flotation. The variation in particle size is shown in Figure 2. The flotation process required a much finer particle size in order to float properly. The maximum particle size changed from 2.0 millimetres for the gravity processes to 0.2 millimetres for froth flotation process.

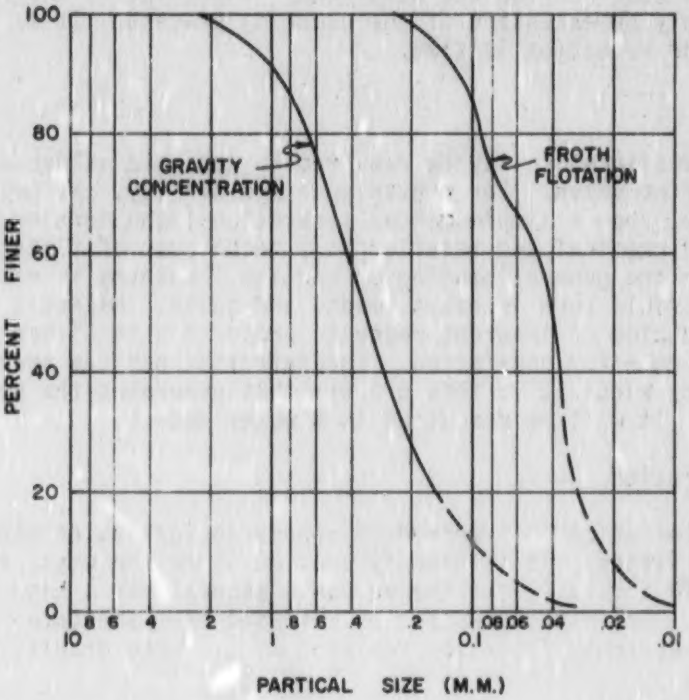


Figure 2. Typical particle size distribution of ore concentration waste.

Metallurgical Processing

The smelting operation is a pyrometallurgical process developed to extract metals from ores or concentrates. The materials are liquified by the application of intense heat; thus, the metals are transferred from the ore to metallic (or sometimes matte) form. Other processes are noted in Table 5.

PROCESSING TECHNOLOGY FOR MAJOR COMMODITIES

The major commodities produced by the mineral industry are grouped into one of two major categories: metallic and non-metallic. Standard production methods for processing the major commodities are discussed further.

Metallics

The major metals produced are subdivided into five groups: base, ferrous, precious, rare, and radioactive. The broad category of base metals includes any of the nonprecious varieties. In general base metals are simply those produced from mineral deposits comprised primarily of sulfides and oxides of copper, lead, and zinc. Iron is the principal

TABLE 5. PROCESSING METHODS AND REAGENTS USED FOR COMMON METALIC ORES

Ore	Process	Reagents	Waste Products
	Base Metals		
Sulfide Copper	Flotation recovery of sulfide mineral concentrates	$Ca(OH)_2$, sulfyhydryl collector, frother	Mill tailings and wastewater
	Pyrometallurgical smelting of concentrates-in which sulfur is driven off, leaving a residue of impure metal (blister copper)	O_2, fuel, reductant, SiO_2, CaO	Flue gas containing SO_2 and other combustion products and slag
	Electro-refining of blister copper to metal product specifications	H_2SO_4, electricity, glue, $CoSO_4$	High salt solution bleed-off and H_2SO_4
Oxide Copper	Sulfuric acid (H_2SO_4) leaching. Process involves partial concentration of impure metals through heap, vat, agitation, or in-situ leaching procedures.	H_2SO_4	Mill tailings and salt solution bleed-off
	Final recovery of metal by scrap iron concentration, electrowinning (EW), or a combination of solvent extraction (SX) and electrowinning (SX-EW).	Scrap iron or ion exchanger, kerosine, electricity	Salt solution bleed-off
Copper Carbonate	Ammonia system leaching-followed by either steam distillation or the SX-EW process to produce copper or metal	NH_3	Mill tailings and wastewater
	Metal recovery through successive steps of pyrometallurgical smelting, and electro-refining.	Na_2S, sulfydryl collection frother, plus pyrometallurgical fluxes and electro-refining reagents as above	Flue gas, smelter slag, and salt solution bleed-off
Native Copper	End product recovery by flotation and smelting	sulfydryl collectors, frother, fluxes, CaO, SiO_2	Mill tailings, flue gas, smelter slag, and wastewater
Lead Zinc	Direct and differential flotation; concentrates may contain recoverable values in copper, gold, and silver.	sulfhydryl collectors, frother, lead promoter (such as thiocarbonalid), $Ca(OH)_2$, NaCN, $CuSO_4$, $ZnSO_4$, zinc promoter, zinc collector	Mill tailings and wastewater, containing cyanide and cyanide degradation products
	Heavy media beneficiation, followed by: differential flotation separation of lead minerals (others): then activation and flotation of zinc (possibly silver)--with concentrates going to pyrometallurgical smelting, electro-winning, or zinc distillation.	Ferrosilicon, flotation reagents as above, smelting or distillation re-agents or electro winning reagents	Mill tailings, flue gas, smelter slag, and wastewater
	Acid leaching of oxidized zinc ores, precipitation as $ZnCO_3$	H_2SO_4, CO_2	Salt solution bleed-off

(Continued)

TABLE 5. PROCESSING METHODS AND REAGENTS USED FOR COMMON METALIC ORES (continued)

Ore	Process	Reagents	Waste Products
	Ferrous Metals		
Iron	Direct smelting of iron ores, through blast furnace reduction of oxides.	Carbon, $CaCO_3$, fuel, CaF_2	Flue dust and gas, blast furnace slag, and wastewater
	Beneficiation of low grade ores (taconite) by flotation of silica to upgrade, or flotation of hematite, followed by pelletizing and indurating.	fatty acids, soap, amine	Tailings and wastewater
	Precious Metals		
Gold-Silver	Gravity separation (placer deposits) by pan; rocker; long tom; sluicing; or tabling.	water	Mill tailings and wastewater (containing suspended solids)
	Amalgamation (on free-milling ore)	Mercury	Mill tailings and wastewater (containing mercury)
	Flotation	H_2O, $Ca(OH)_2$, frother (alcohol, pine oil etc.); collectors (sulfhydryl, dithiophosphate, soap etc.) with usual dosage at 0.01 to 0.05 lb/ton ore	Mill tailings and wastewater
	Cyanidation: by vat leach, and zinc precipitation; by agitation leach, countercurrent decantation (CCD), and zinc precipitation; by flotation concentration, leach, and zinc precipitation; by a combination of vat leach on sands and agitation leach on slimes, followed by CCD and zinc precipitation; and by heap leach, carbon absorption, and electrolysis on steel wool cathodes.	NaCN, Zn, CaO, electricity	Mill tailings and leach solution containing traces of cyanide and cyanide degradation products
	Smelting: Direct smelting of high-grade or flux-type ore (high silica content).	fuel, CaO, SiO_2, O_2	Smelter slag, iron, and lime

(Continued)

TABLE 5. PROCESSING METHODS AND REAGENTS USED FOR COMMON METALIC ORES (continued)

Ore	Process	Reagents	Waste Products
	Rare Metals		
Molybdenum	Primary molybdenum Sulfide flotation; can be followed by roasting to oxide or by thermite reduction to ferromolybdenum.	Pine oil, vapor oil, sytex, lime, sodium silicate, nokes reagent (NaOH, P_2S_5)	Mill tailings and wastewater (containing trace amounts of flotation reagents)
	By-product molybdenum from porphyry copper operations (sometimes involves roasting), flotation separation from copper minerals; can be roasted to oxide.	Xanthates, dithiophosphate, dithiocarbamate, fuel oil, NaCN, yellow prussiate of soda, nokes reagents (NaOH, P_2S_5) Na_2S, NaHS, $(NH_4)_2S$, dextrine, NaOCl, H_2O_2, antifoams, $Na_2Zn(CN)_4$	Wastewater containing metal cyanides and cyanide degradation products
	Sulfide and non-metallic flotation of complex chalcopyrite-molybdenite-powellite ore, using straight sulfhydryl flotation beneficiation for separation of chalcopyrite and molybdenite, bulk flotation of scheelite-powellite, pressure soda ash digestion of these minerals, and either chemical or SX separation of tungsten and molybdenum into pure chemical salts.	Sulfhydryl flotation reagent, frother, Na_2CO_3, soap, quebracho, H_2SO_4, NaHS, $CaCl_2$, NaOH or SX-separation and precipitation	Mill tailings and wastewater and chemical plant wastewater containing numerous metallic ions and complex anions
Tungsten	Gravity separation of scheelite.	water	Mill tailings and wastewater
	Flotation beneficiation of scheelite (best in absence of powellite, fluorite, or calcite).	soap, Na_2CO_3, quebracho	Mill tailings, wastewater (containing Na_2CO_3)
	Flotation beneficiation of scheelite-powellite followed by pressure soda ash digestion and either chemical or SX separation of tungsten-molybdenum in solution and final precipitation of the pure salts.		Mill tailings and wastewater and chemical plant wastewater containing numerous metallic ions and complex anions
	Radioactive Metals		
Uranium	Acid leach with oxidant, liquid solid separates by CCD, solvent extraction (SX), and alkali precipitation; sand-slime, resin-in-pump, and alkali precipitation; and CCD, column ion exchange (IX), and alkali precipitation.	H_2SO_4, MnO_2, $NaClO_3$, $Fe_3(SO_4)23$· H_3PO_4 (rare), NaCl NaOH	Mill tailings (which are nearly as radioactive as the mill feed) and wastewater containing radioactive daughter products, and dissolved salts
(Continued)			

TABLE 5. PROCESSING METHODS AND REAGENTS USED FOR COMMON METALIC ORES (continued)

Ore	Process	Reagents	Waste Products
Uranium - (continued)	Alkali leach, carbonate-bicarbonate, with oxidant, autoclave leach, sand-slime separation, CCD, resin-in-pulp, and alkali precipitation; autoclave leach, filtration for clear solution recovery, and alkali precipitation.	$NaClO_3$, $NaHCO_3$, Na_2CO_3, NaOH, O_2	Mill tailings (which are nearly as radioactive as the mill feed) and wastewater containing radioactive daughter products, and dissolved salts
Uranium-Vanadium	Salt roast of carnotite ore, water leach for vanadium, followed by vanadium red-cake precipitation, acid leach for uranium and additional vanadium recover, IX recovery of uranium, alkali precipitation of yellow cake; and carbonate-bicarbonate quench, chemical separation of uranium and vanadium, precipitation of yellow cake.	NaCl, Na_2CO_3, NaOH, fuel, CO_2	Mill tailings (which are nearly as radioactive as the mill feed) and wastewater containing radioactive daughter products, and dissolved salts

commodity of a separate group known as the ferrous metals. Gold and silver are the common precious metals. Rare metals of importance include molybdenum and tungsten. Naturally radioactive elements, a small group with steadily increasing cultural and ecological impact, occur mainly in uranium and vanadium ores. The various processing techniques used in these industries are summarized in Table 5. Also shown are the reagents used in processing and the expected waste products. Normally, all liquid and solid wastes are disposed of in the tailings pond; however, in past times, careless operators may have allowed the direct discharge of the waste stream into receiving waters.

Nonmetallics

Historically, the heterogeneity of nonmetals has precluded their classification into logical and systematic categories. Inexact chemical compositions, diverse products and end-uses, widely variable chemical and physical properties within complex mineral groups, and other overlapping characteristics contribute to the classification problem. By convention, non-metallics are classified by the commercial-end use; agriculture, construction, and industry. Chemical substances included in each of these commercial categories of nonmetallic minerals are outlined in Table 6.

TABLE 6. CLASSIFICATION OF NONMETALLICS

Commercial Category	Use	Chemical Substance
Agriculture	Plant Nutrients and Solvents	Elemental Phosphates Potash Salts Sulfates
Construction	Dimension Stone, Lime, Rock, Foundations, Cements, Insulation	Carbonates Silicates Sulfates
Industry	Abrasives, Acids, Brines, Clays, Metallurgical, Multipurpose Refractories	Carbonates Elemental Halides Hydroxides Phosphates Potash Salts Silicates Sulfates Sulfides

In many instances, production techniques for the nonmetallics are similar to those used in producing metals. With a few exceptions, the bulk of industrial minerals may be produced through less complex operations, especially in processing. A few of the important commodities require flotation, electro-magnetic separation, air classification, or other sophisticated separation methods. Generally, the reagents used are less reactive and the waste products more inert than those used in the production of metals.

WASTE DISPOSAL

In the 19th and early 20th Centuries many mine and mill operations discharged solid and liquid waste products with no regard for the environmental effects of the wastes. Mills were frequently located alongside waterways where waste products were often discharged. Tailings were often placed carelessly which accelerated erosion and subsequent sedimentation of tailings materials.

Solid Wastes

It is inevitable that waste materials will result from mineral industry operations. Solid wastes developed include overburden from surface mining, barren or low grade (non-economic) portions of all mineral or ore deposits, and tailings remaining from mineral processing.

The heterogeneous nature of most overburden restricts its practical usage for any purpose other than as crude fill material. With planning and foresight, however, the mine operator will remove the topsoil separately from other portions of the overburden, thereby saving a valuable asset needed for use in later reclamation.

Other solid wastes that accumulate during mining include: rock materials generated through surface facility excavation; pre-production mine development; weakly mineralized (uneconomic) portions of the deposit which are broken and removed, as required, to gain access to minable portions of the orebody. The coarse size and mixed nature of this type of waste material limits its practical uses to land fill, railroad ballast, and, in some instances, highway and gravel road construction. However, favorable economics created by special situations have resulted in several profitable ventures. A notable example is the limestone by-product business of major zinc mining companies operating in Tennessee.

The high concentration of minerals in tailings is both an asset and liability. Increased pollution could result but secondary recovery is possible.

Frequently a metallurgist considers old tailings piles as a potential ore body. Some tailings contain valuable by-products that were not recognized or of economic value during active mining. For instance, porphyry gangues frequently contain appreciable amounts of potassium and phosphorous. The extraction of these elements may become desirable when present deposits are depleted.

Liquid Waste

Two liquid waste streams may be expected during an active operation: a processing waste and water removed from the workings. The processing waste may contain various concentrations of processing chemicals which were shown in Table 5 while the water from the workings may be a mineralized acidic discharge. Upon mine shutdown, the discharge of the processing waste will cease but an acid mineralized discharge may be expected from free draining workings. The erosion of tailing may result in the deposition of solid mine waste in receiving waters. The details of formation, transportation, and removal systems of mineralized discharges are discussed in Section 5.

HISTORICAL MINERAL AND WASTE PRODUCTION

The mineral industry in the United States has produced in excess of 70 mineral resources. A national summary of the historical production of metals and the associated waste is presented in Table 7. Production figures for each state and a geographical distribution of commodities mined are presented in Appendix C.

The historical production figures are based on data from the United State's Bureau of Mines Mineral Yearbooks. Historical records are incomplete which explains the varying base data. The tailings and waste figures were developed from the production figures using the following assumptions:

- Tailings volumes were calculated by dividing the percent occurrence into the production (except for gold, silver, and iron ore).

- Since gold is often a by-product of copper mining, only 53 percent was assumed to be primary production. Thus, the tailings volumes were calculated as above, but reduced by a factor of 0.53.

- Silver is often a by-product of copper, lead, and zinc mining, the primary production was assumed to be 50 percent. The tailings volumes were calculated as above, but reduced by a factor of 0.50.

- Iron ore tailings were assumed to equal production because iron ore is commonly shipped directly to the blast furnace. The volume of waste was assumed to equal the production figure.

- Waste figures (except iron) were calculated by assuming an average stripping ratio of 2.5.

TABLE 7. SUMMARY OF HISTORICAL PRODUCTION OF MAJOR METALS AND POTENTIAL WASTE GENERATED [a]

Metal	Production (Metric tons thousands)	Production Base Dates	Assumed Occurence in ore (percent)[a]	Tailings (metric tons millions)	Tailings and Waste (metric tons millions)
Base Metals					
Copper	57,800	1845	1.0	5,780	14,450
Lead	30,900	1873	2.0	1,550	3,875
Mercury	120	1850	0.5	24	60
Zinc	35,300	1873	4.0	883	2,208
Ferrous Metals					
Iron Ore	5,420,000	1834	50.0	5,400	5,400
Precious Metals					
Gold	10	1792	0.00086	616	1,540
Silver	153	1834	0.014	546	1,365
Rare Metals					
Molybdenum	1,294	1914	0.3	430	1,075
Tungsten	140	1900	0.5	28	70
Uranium	253	1957	0.25	101	253
Total				15,358	30,296

[a] Historical production between production base data to present.
[b] The percentages are a synthesis of published data and the author's experience in mining.

SECTION 5

POLLUTANTS ASSOCIATED WITH MINING

The chemistry of acid mine drainage (AMD) and heavy metals is extremely complex and not fully understood. This section will define the mechanisms involved in pollutant formation and transportation; their complex interactions in an aqueous environment; and their removal systems. Information is also presented on the relative toxicities and biological effects of the pollutants to aquatic life and to municipal and agricultural uses.

Pollutants in river and stream systems will be discussed in the greatest detail because they have suffered the greatest impact from mining. Mine drainage effects on lakes and groundwater systems will be discussed separately. Acid mine drainage and heavy metal pollution are discussed throughout, whereas only the formation and removal mechanisms of sediment pollution are discussed. The impact of sediment is discussed in greater detail in Section 6 under the heading of "Loading Functions".

FORMATION OF POLLUTANTS

Acid and base metal liberation is a natural weathering process and in some instances acid drainages containing high metal concentrations are found in an environment undisturbed by man's activities. Unfortunately, in many cases, indiscriminate mining practices have greatly accelerated this process and as a result have severely impacted water quality of receiving waters. The following is a discussion of the major processes involved in the formation of pollutants.

ACID MINE DRAINAGE (AMD)

The results of this study indicate that AMD has contributed to water quality degradation at approximately 60 percent of the sites where inactive mines are a source of pollution. Acid mine drainage is the result of the oxidation of many base metal sulfide compounds. The most abundant of these compounds are iron sulfides of which pyrite (FeS_2), marcasite (FeS_2) and pyrrhotite (Fe_5S_6 to $Fe_{16}S_{17}$) are the most common. Hereafter, for simplicity, the term "pyrite" will refer to all iron sulfides. Investigators generally agree that the oxidation of pyrites is the predominant source of AMD [Hill 1975a, Colorado Water Conservation Board 1974].

This oxidation process would not manifest itself if the pyrite were left in its naturally reducing environment. During mining operations, pyrites may be exposed to air in underground workings or above ground in open pits, over-burden piles, and tailing piles. Regardless of the location, acid is formed if the pyrite comes in contact with oxygen and water.

Pyrite Oxidation Model

Acid is formed as a result of a series of interrelated reactions which are given below for the pyrite system:

$$\underset{\text{Pyrite}}{FeS_2(s)} + \frac{7}{2}O_2 + H_2O \longrightarrow \underset{\text{Ferrous Ion}}{Fe^{+2}} + 2SO_4^{=} + 2H^+ \qquad (1)$$

$$\underset{\text{Ferrous ion}}{Fe^{+2}} + \frac{1}{4}O_2 + H^+ \longrightarrow \underset{\text{Ferric ion}}{Fe^{+3}} + \frac{1}{2}H_2O \qquad (2)$$

$$Fe^{+3} + 3H_2O \longrightarrow Fe(OH)_3 + 3H^+ \qquad (3a)$$

Ferric ion — Ferric Hydroxide

$$2Fe^{+3} + XH_2O \longrightarrow Fe_2O_3 \cdot XH_2O + 6H^+ \qquad (3b)$$

Ferric ion — Hydrous Ferric Oxide

$$FeS_2(s) + 14Fe^{+3} + 8H_2O \longrightarrow 15Fe^{+2} + 2SO_4^{-2} + 16H^+ \qquad (4)$$

Pyrite + Ferric Iron — Ferrous Iron

When pyrite is exposed to oxygen and water, the sulfide is initially oxidized to sulfate releasing acid, sulfate, and ferrous iron (Reaction 1). The ferrous iron, which is many times more soluble than ferric iron, is ultimately oxidized to ferric iron (Reaction 2). At normal pH ranges (6-8) ferric iron hydrolyzes forming acid and an insoluble, hydrated ferric oxide (Reaction 3b) which occurs as a gelatinous floc (yellow boy) and precipitates or adsorbs onto surfaces over which it flows. Frequently, the precipitate is shown as ferric hydroxide (Reaction 3a).

An alternate pathway for the oxidation of pyrite is shown by Reaction 4. Ferric iron, dissolved due to the depressed pH of the solution from the initial formation of acid, oxidizes the sulfide to sulfate and is itself reduced to the ferrous form. Regardless of the pathway taken, the net result is the same. By summing Reactions 1 through 3, shown by Reaction 5, the oxidation of one mole of pyrite produces four equivalents of acidity.

$$FeS_2(s) + \frac{15}{4}O_2 + \frac{7}{2}H_2O \longrightarrow Fe(OH)_3(s) + 2H_2SO_4 \qquad (5)$$

Mechanisms and Rates of Oxidation

Stumn and Morgan have presented a model describing the oxidation of pyrite shown by Figure 3 [Stumm 1970].

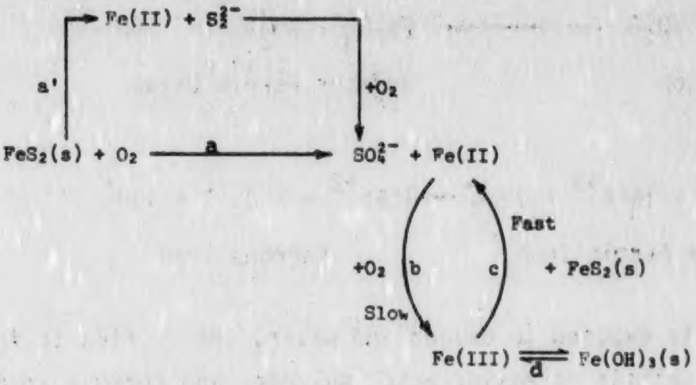


Figure 3. Pyrite oxidation model [Stumm and Morgan 1970].

The initial step in the sequence is the oxidation of pyrite (a) or pyrite may be dissolved and then oxidized (a'). In either case the principal oxidant is molecular oxygen. The ferrous iron is then slowly oxidized to ferric iron (b) which may then rapidly oxidize pyrite (c). Once this sequence is initiated, oxygen is utilized only to oxidize ferrous iron. This reaction is schematic and is not intended to specify the exact mechanistic steps involved. The rate determining step in this scheme is the oxidation of ferrous iron (Reaction b). Singer and Stumm determined Reaction (b) to be much slower than (a). This conclusion is supported by others who discovered that a biological system, catalyzed by anaerobic microorganisms, produced only acid and ferrous iron [EPA 1970a].

The importance of molecular O_2 versus ferric iron as the principal oxidant of pyrite is not fully known. Wentz reported that the rate of O_2 oxidation increases with O_2 concentration and with pH's higher than 3 [CWCB 1974]. On the other hand oxidation by ferric iron increases with the ratio of Fe^{+3}/Fe^{+2} and with the total dissolved iron concentration. This ratio and the dissolved iron concentration both decrease with increasing pH [CWC 1974].

Singer and Stumm, as reported by Wentz, indicated that the rate of oxidation of pyrite is the same in the presence of Fe^{+3} regardless of the presence of oxygen. It was also shown that this oxidation does not occur at detectable rates in the absence of Fe^{+3}. A strong case is presented for the theory that the principal oxidant of pyrite is dissolved ferric iron. Although it appears that O_2 plays a minor role, it should not be forgotten that without the initial oxidation of sulfide and ferrous iron by O_2, no ferric iron could be formed [CWC 1974].

If the ferric iron oxidation of pyrite is to remain predominant over O_2 oxidation, the rate of conversion of ferrous to ferric must be accelerated. Stumm and Lee reported that dissolved divalent copper and manganese increase the rate of ferrous iron oxidation [Stumm 1961]. They also determined that micro-organisms appear to play a significant role in catalyzing the oxidation of ferrous iron. Ferrobacillus ferrooxidans, F. sulfoxidans, and Thiobacillus thiooxidans are the micro-organisms involved [EPA 1970a]. These aerobic acidophilic chemo-autrophic bacteria are active at pH ranges of 2 to 4.5, obtain energy from the oxidation of ferrous iron, and their carbon source is CO_2.

Law and others concluded that there is sound evidence that bacterial catalysis of pyrite oxidation may only occur in significant amounts in surface environments such as spoil and tailings piles [Third Symposium Coal Mining Drainage 1970]. It was also concluded that bacterial catalysis is less likely to occur in underground environments.

In summary it can be concluded that:

a. The principal oxidant of pyrite is ferric iron.

b. The apparent rate limiting step is the oxidation of ferrous iron by oxygen. This reaction is catalyzed by dissolved copper and manganese, both of which are usually present in metal mines.

c. Oxidation of ferrous iron is also catalyzed by microbial action which is most significant at or near a surface environment at pH ranges between 2 and 4.5.

Frequently the overall reaction will not occur at a specific location but will occur as the water flows through the pyrite and on downstream. For example, the initial reaction will occur wherever the pyrite exists in the tailings pile or in the mine workings. After Reaction 1, the ferrous iron is in a soluble form in the low pH water and is free to move with the water. Therefore, Reaction 2 is free to occur away from the actual site of the sulfide oxidation. Reaction 3 does not occur sufficiently until the low pH of its transport water is neutralized. This buffering may occur as a result of stream alkalinity or the acid water flowing over natural calcareous formations.

HEAVY METALS

In approximately 50 percent of the cases of pollution reported in this study, metallic ions were reported in sufficiently high concentrations to be harmful to aquatic life, either independently or synergistically. The most commonly noted metals are copper, iron, manganese, and zinc. However, local mineralogic and lithologic conditions may result in the solution of other metals.

The weathering process of other base metal sulfides is similar to the process described for pyrite but may not produce acid.

Mining activities accelerate the weathering process by removing material from a naturally reducing environmemt, increasing its surface area by fracturing, and exposing it to elements needed for oxidation (i.e., water and oxygen). In addition, tailings often have a high concentration of other minerals which were not recovered in the mining operation. During active mining the operator will extract only those minerals from the gangue which are economically feasible. Historically many ores such as pyrite, copper, lead, and zinc were overlooked in the search for gold.

The Penn Mine slag dump (CA-6) is an example of high metals concentrations in the tailings. The area was mined for copper from the 1860's to 1919 when the smelter was closed. Wiebelt and Ricker have analyzed the tailings and found the average copper and zinc content to be 0.37 and 6.47 percent respectively [U.S. Bureau of Mines 1948]. Zinc concentrations of present mining operations may be expected to range between 2 and 10 percent. Thus if the mine were being worked in today's economic market, the zinc would undoubtedly be recovered.

The disolution of heavy metals is greatly accelerated when the pH of the solution passing over the mineral is lowered. The relationship between pH and solubility of several metals, in distilled water, is shown in Figure 4. The linearity of many of the solubilities may only be expected in the pH ranges shown and should not be extrapolated further. The solubilities increase by orders of magnitude for each unit the pH is lowered assuming theoretical complete ionization.

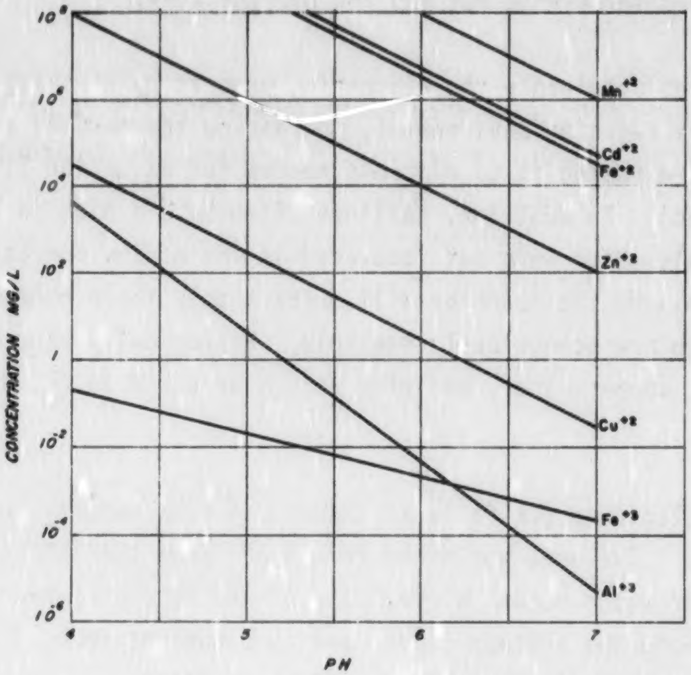


Figure 4. Solubilities of oxides and hydroxides of various metals [Stumm and Morgan 1970].

Solubility, or more realistically stability, is also a function of temperature, concentration of other dissolved ions, and the oxidation-reduction (redox) potential of the solution. Redox potential is commonly measured in volts or millivolts and is represented by Eh. The relationship of the redox potential and acidity-alkalinity conditions to the stability of sulfide minerals in natural aqueous environments has been discussed by Garrels [ERDA 1975]. A graphic method of presenting this data is the Eh-pH diagram. Unfortunately, there is no accepted sign convention. The European convention represents oxidizing reactions with a positive sign and reduction by a negative. Most American physical chemists use the opposite convention. Garrels uses the European convention (oxidation +) and for clarity this convention will be used for the remainder of this report.

Figure 5 is an Eh-pH diagram representing the stability relationships of iron oxides and sulfides in water. This concept is expanded further in Figure 6 which represents the stability of copper and iron sulfides and oxides. The figures demonstrate the complexity of the concept of stability of the various mineral forms.

As an example, Ross observed a pH of 1.4 in a drainage pond from a mine in the Rocky Mountains. The typical redox potential of these waters was found to be approximately 450 mv [EPA 1973m]. It can be seen from Figure 6 that at these values both copper and iron will exist in the divalent state. Waters such as this generally are capable of rapidly solubilizing much more metals than waters at a neutral pH (6-8) with a low redox potential.

The potential for metal liberation is probably the greatest where acid is formed in the absence of calcareous formations, which tend to buffer the water. This theory is supported by the work of Caruccio, who found that the degree of acidity is a function of the calcium carbonate content of the natural rock strata, the pH of the natural waters prior to mining, and the physical state (i.e. crystallographic structure) of the pyrite [EPA 1973m].

SEDIMENTATION

The production and distribution of sediments into receiving waters is a natural continuing process of landform development. This process has been accelerated by many of man's activities, such as erosion of tilled

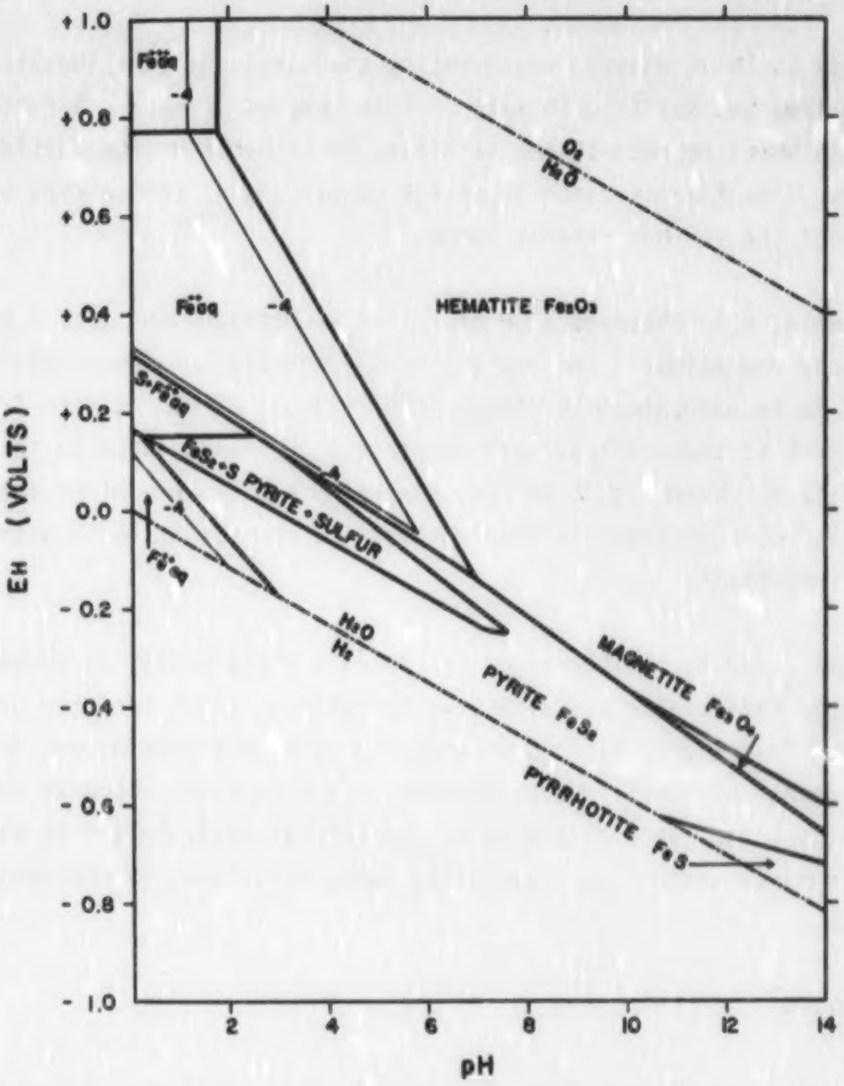


Figure 5. Stability of iron oxides and sulfides [Garrels and Christ 1965].

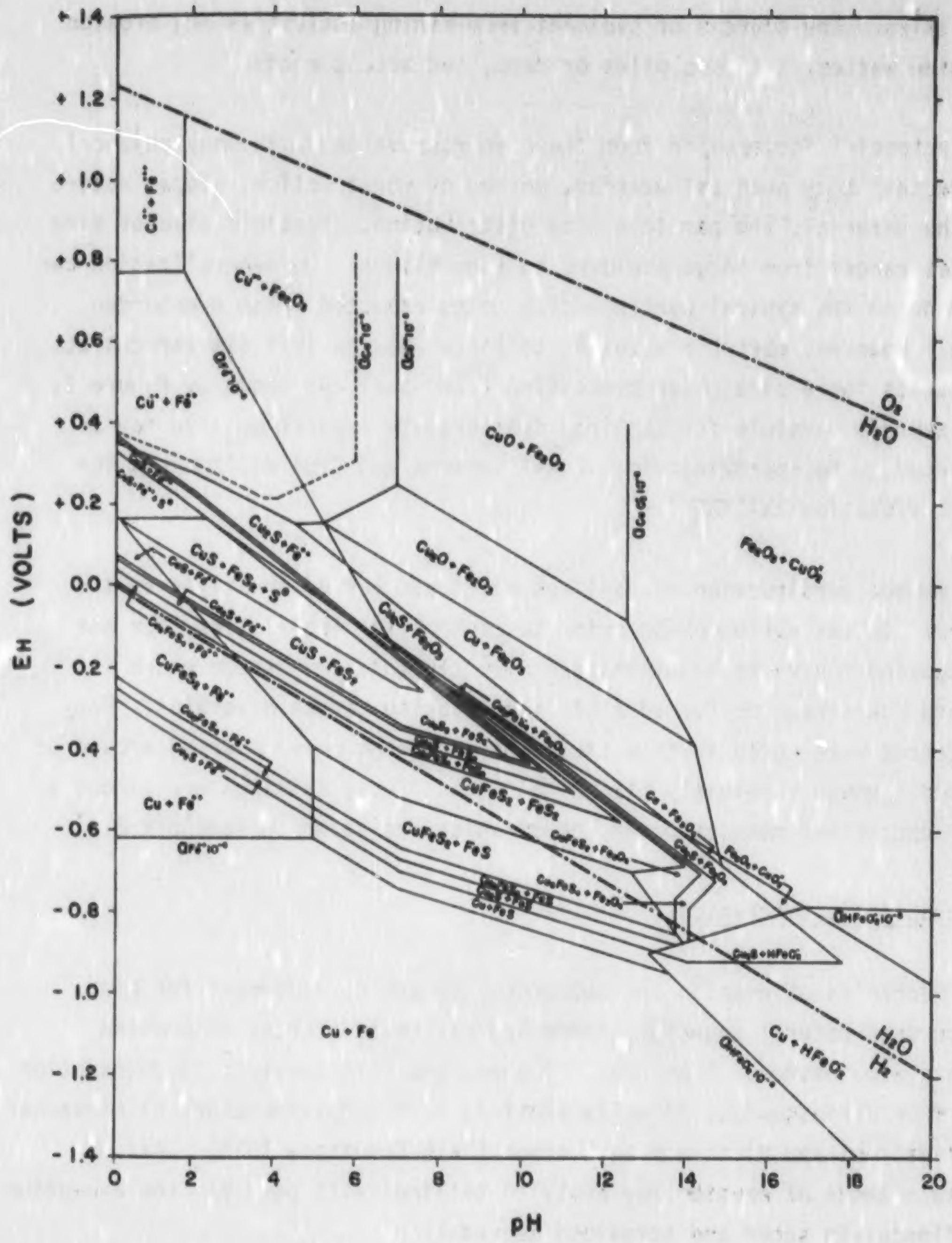


Figure 6. Stability of iron and copper oxides and sulfides [Garrels and Christ 1965].

lands, mining and new construction of homes, factories, highways, and utilities. The sources of sediment from mining activities are erosion of mine wastes, tailings piles or dams, and access roads.

The potential for erosion from these sources varies with many physical characteristics such as: weather, method of construction, slope, nature of the material, and particle size distribution. Particle size of mine wastes ranges from large boulders to fine slimes. No generalization can be made on the typical particle size to be expected in an overburden pile. However, particle sizes in tailings will exhibit similar characteristics for a particular processing technique. As shown by Figure 2, the average particle for tailings from gravity separation size may be expected to be approximately 0.2 millimetres and 0.04 millimetres for froth flotation tailings.

The method construction of tailings piles has varied greatly over the years. It was not uncommon prior to controlling legislation, for the processing slurry to be discharged directly into the stream where it washed downstream or formed a blockage causing stream diversion. Many instances were noted in this study where streams were diverted around or flowed through carelessly placed tailings. Today tailings are placed by more controlled methods, examples of which are shown in Appendix B.

Transportation Mechanics

The mechanics of erosion and sedimentation are no different for mine waste than natural sources. There are six basic sources of erosion within a watershed. They are: 1) sheet and rill erosion; 2) degradation of minor drainageways; 3) gully erosion; 4) floodplain scour; 5) streambed degradation; and 6) stream bank scour [Task Committee 1970]. All of these methods of erosion may apply to tailings with possibly the exception of floodplain scour and streambed degradation.

Sediment is transported in streams by wash load and bed load. The wash load is composed of fine particles entrained in runoff which are relatively insensitive to flow parameters. The bed load is composed of coarse particles dependent on the energy of a stream. Erosion of tailings may thus be expected to have a greater potential long range impact on the character of the wash load and a short range impact on the bed load.

ACID AND METALS IN RECEIVING WATERS

The impact of mine drainage on a stream system may be severe. Often the equilibrium or natural buffering capabilities of the stream are upset to such a degree that aquatic life is depressed or destroyed for many kilometres. This buffering system is vitally important in streams receiving acid discharges. The following discussion will review the buffering system and transporation mechanisms for river and stream systems. Known instances of degraded water quality in lakes and groundwater systems are discussed separately.

NATURAL BUFFERING SYSTEMS IN STREAM SYSTEMS

Alkalinity is described as the ability of water to neutralize acid. Bicarbonate and carbonate are the principal sources of alkalinity in most surface waters. It is generally thought that alkalinity is released into surface water by the dissolution of minerals such as limestone and feldspar [Stumm 1970].

Carbon dioxide, which is abundant in the atmosphere, readily dissolves in water forming carbonic acid in accordance with Reaction 6:

$$CO_2 + H_2O \longrightarrow H^+ + HCO_3^- \qquad (6)$$

The solution process will continue until the following equilibrium is reached.

$$\frac{[H^+]\,[HCO_3^-]}{[CO_2]} = K \qquad (7)$$

The result of this process is the formation of waters with a slightly acidic and agressive nature. If this water flows over a calcareous formation, such as limestone, the following reaction occurs:

$$CaCO_3 + H^+ + HCO_3^- \longrightarrow Ca^{++} + 2HCO_3^- \qquad (8)$$

The degree of carbonation occurring coupled with the potential for reaction with calcareous materials thus develops the basic buffer system in most natural waters. When acidic mine drainage combines with these waters the following reaction occurs:

$$H^+ + SO_4^= + Ca^{++} + HCO_3^- \longrightarrow Ca^{++} + SO_4^= + H_2O + CO_2 \qquad (9)$$

Thus, the natural buffering system is destroyed if the added acidity is greater than the capacity of the buffer system; after this occurs the pH will drop to a low steady state value.

As the stream continues downstream the resulting low pH waters will meet with other inflowing buffered waters resulting in the gradual restoration of neutral conditions in the stream. Thus the length of the stream exhibiting low pH conditions will be a function of: 1) the AMD reaching the stream; 2) the buffering capacity of upstream waters; 3) the buffering capacity of downstream waters joining the stream. Pyrite containing ores are usually found in acid igneous deposits. Since the calcareous minerals are rare in these deposits, the impacted length of stream may be quite long.

SULFATE AS AN INDICATION OF AMD

The non-conservative nature of the reactions occurring in the AMD cycle makes prediction of the scope of the problem difficult. An estimate of the quantity of acid produced may be made by analyzing the increase in sulfate concentrations above background.

It can be seen by reviewing Reaction 5 that the sulfate content of waters will be generally related to acidity potential. The relationship is non-linear because the acidity generated is a function of the oxidation state of the iron, hence the term acidity potential.

The significance of sulfate measurement is more obvious when it is realized that, at a particular point in a system, iron may exist in the ferrous or ferric state. As the ferrous iron is gradually oxidized, more acid will be released into the system. The sulfate concentration will therefore remain constant unless the stream is diluted. When dilution occurs, as is the case in many of the affected stream systems, a careful mass balance approach in analyzing sulfate, iron, and acid concentrations can give an indication of the magnitude of AMD pollution.

A pitfall in the sulfate tracer system may arise in the presence of large amounts of limestone, or in areas of naturally occurring sulfate as is the case in many waters in highly mineralized areas. Sulfate may precipitate from solution, in the presence of high calcium concentrations, as calcium sulfate ($CaSO_4$). Calcium sulfate has a solubility product of 2.5×10^{-5}. As an example, Figure 7 is a plot of the solubility of $CaSO_4$ in distilled water. These concentrations will vary with temperature and concentration of other ionic species.

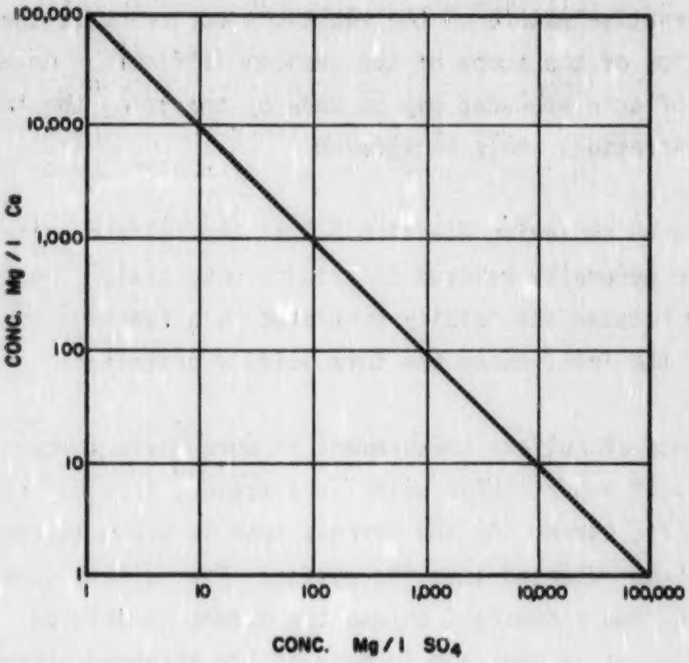


Figure 7. Solubility of calcium sulfate.

TRANSPORATION AND REMOVAL OF POLLUTANTS IN STREAMS

The composition of mine drainage is complex and may be expected to vary for each mine or mining area. These variabilities make a mine drainage system difficult to model in generalized terms. It was decided to use a specific polluted stream system as an example of what can be expected to result from acidic discharge with high metal concentrations.

The Kerber Creek area of Colorado (CO-8) was selected as both a representative site and one which has been analyzed at significant level of detail. The area contains an adit drainage and the stream flows through tailing piles which also contribute pollution. The area has been the subject of extensive analysis by Wentz [EPA 1973g, USGS 1974a]. It is located in the south central portion of the state near the town of Bonanza at the northeast edge of the San Juan volcanic field.

The location of the mine and tailings deposits are shown on Figure 8. Water quality in Kerber Creek has been degraded by acid and metals to the confluence with the San Juan River, a distance of approximately 36 kilometres. Wentz observed that the upper tailings were the largest contributor of metals to the creek, probably due to less efficient mining operations [USGS 1974a]. Metals concentrations from the adit generally decline as the winter progresses and begin to increase in May during the onset of snowmelt. Low-flow pH values are the highest in the winter and show a sharp drop with the onset of snowmelt in May and rise again in June. This is probably due to an initial flushing action in May and dilution with heavy flows in June.

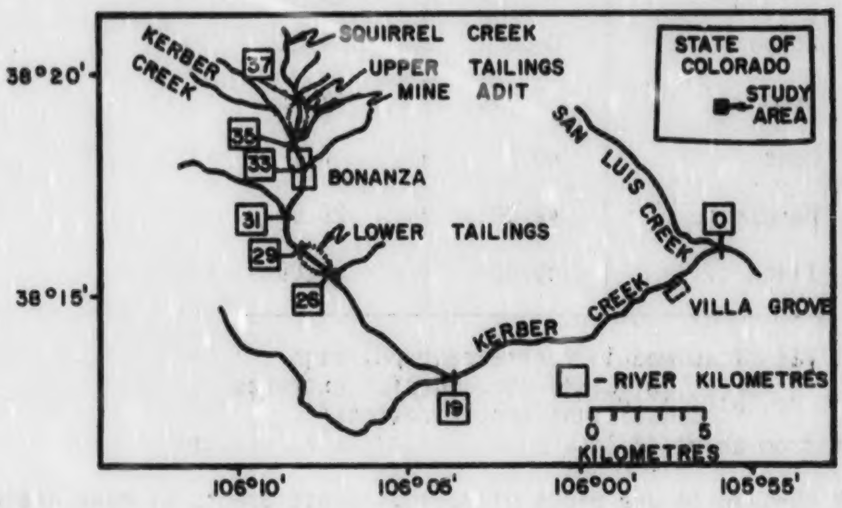

KERBER CREEK
37
SQUIRREL CREEK
UPPER TAILINGS
MINE ADIT
35
33
BONANZA
31
LOWER TAILINGS
29
26
SAN LUIS CREEK
0
VILLA GROVE
KERBER CREEK
19
STATE OF COLORADO
STUDY AREA
- RIVER KILOMETRES
0 5
KILOMETRES
38°20'
38°15'
106°10'
106°05'
106°00'
105°55'

Figure 8. Kerber Creek and vicinity.

Initial Effect on Stream Quality

The quality of water discharged into the stream may be seen by reviewing the adit discharges. The creek flows through the tailings making discharge there diffuse and impractical to measure. The range of concentrations of metals from the adit discharges, measured between October 1972 and June 1973, are shown in Table 8. These concentrations are not the worst observed in this study; but the area was selected as an example because of the availability of data.

TABLE 8. DRAINAGE OF THE RAWLEY MINE [USGS 1965]

	Concentration[a]	
Constituent	Low	High
pH	3.4	3.6
Alkalinity	0	0
Cadmium	0-10	0-26
Copper	0-50	4.00
Iron	7.40	12.00
Lead	<0.1	0.1
Manganese	42.00	29.00
Zinc	48.00	29.00

[a] Measured in mg/l except pH, high and low values shown depict extremes in constituent concentrations observed.

Figures 9 through 14 are plots of various constituents of mine drainage in Kerber and Squirrel Creeks plotted from the confluence with the San Juan River (0 kilometres) to the stream above the mine drainage. The mine drainage has essentially all been discharged into the creek by

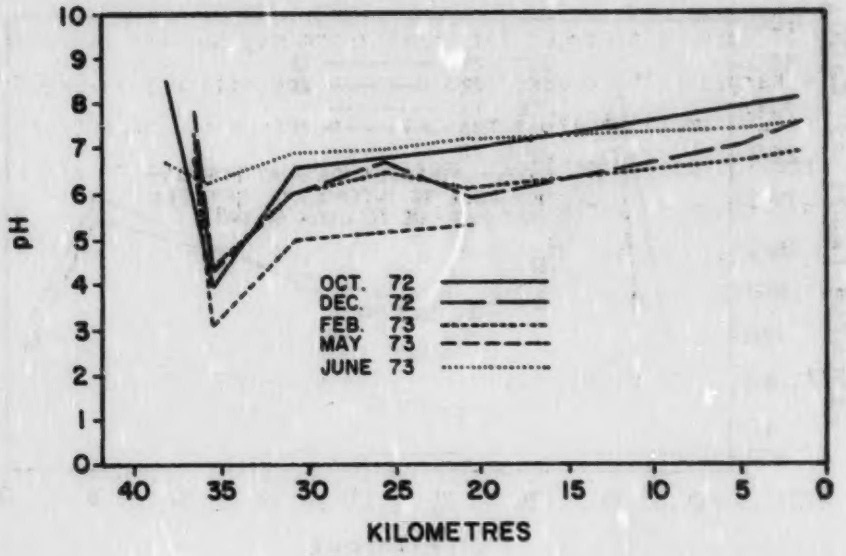


Figure 9. The pH in Kerber Creek.

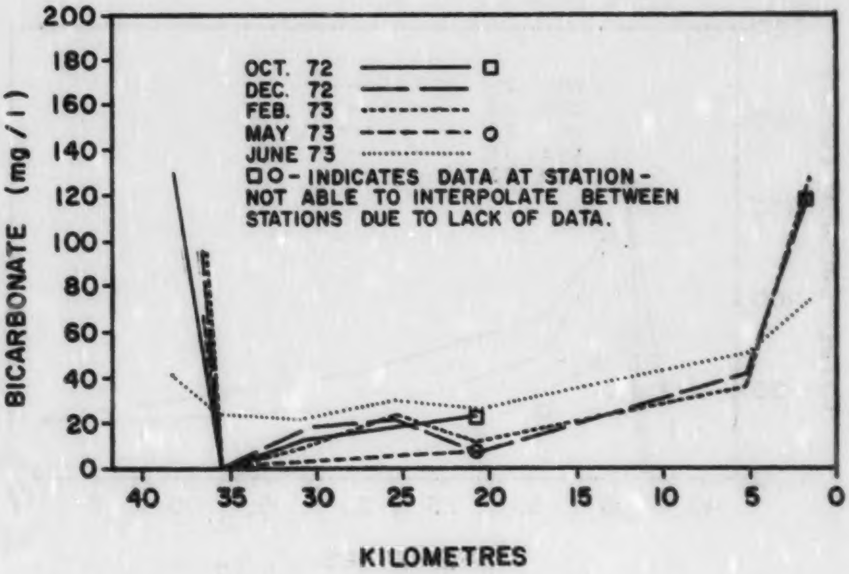


Figure 10. Bicarbonate concentrations in Kerber Creek.

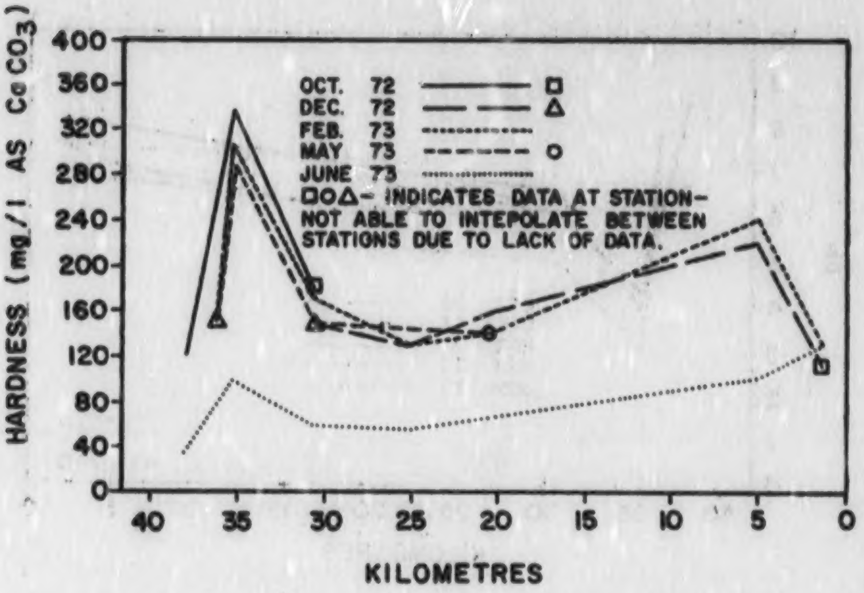


Figure 11. Hardness concentrations in Kerber Creek.

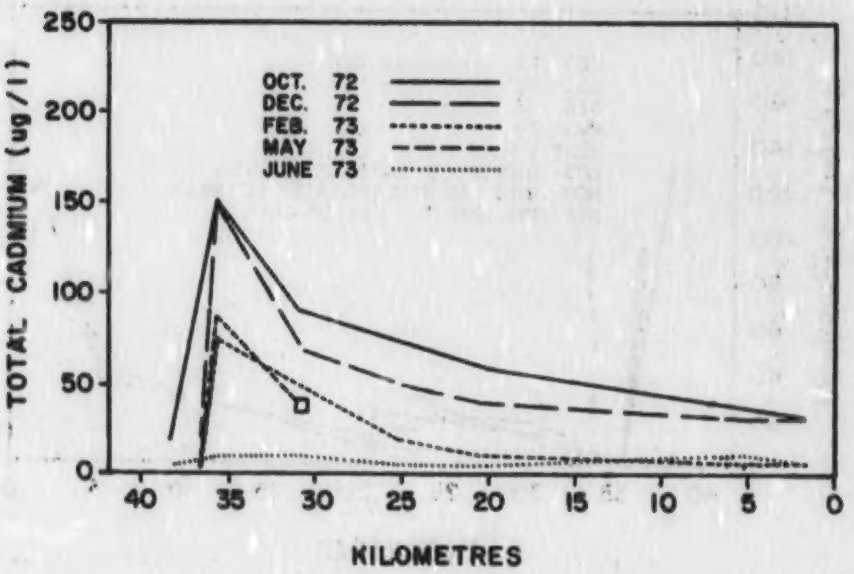


Figure 12. Total cadmium concentrations in Kerber Creek.

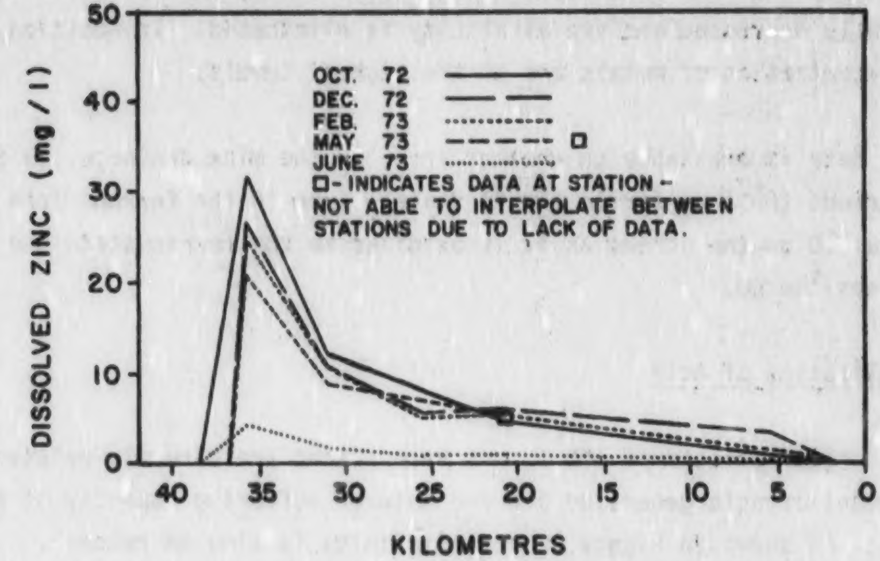


Figure 13. Dissolved zinc concentrations in Kerber Creek.

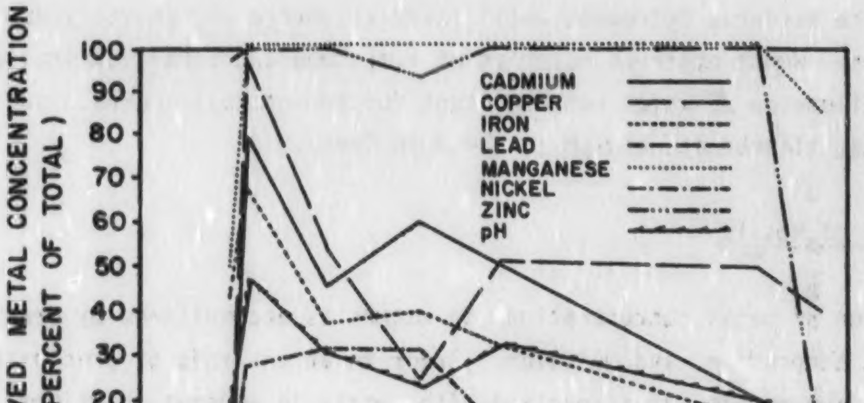


Figure 14. Percent of dissolved metals in Kerber Creek.

river-kilometre 35. At this point, as shown in Figures 9 and 10, the pH is greatly depressed and the alkalinity is eliminated. In addition, the concentration of metals are at the highest levels.

Little data is available on whether iron, in the mine drainage, is in the ferrous (F^{+2}) or ferric (Fe^{+3}) state. Iron in the ferrous form may exert a COD on the stream as it is oxidized to the ferric state and depresses the DO.

Neutralization of Acid

The potential effects of AMD on a stream system are directly related to the amount of acid generated and the natural buffering capacity of the stream. As shown in Figure 10 the alkalinity is slow to recover. Inflow from less acidic sidestreams dilutes the H^+ concentrations and adds bicarbonate which further raises the pH. The creek increases in hardness where the mine discharges (shown in Figure 11); from this point the hardness decreases until river-kilometre 25, possibly due to dilution. Wentz observed outcrops of limestone and alkali springs at river-kilometre 25 which would account for the gradual increase in hardness, bicarbonate and pH to San Juan Creek.

Removal of Metals

Reduction of metal concentrations in waters is accomplished by precipitation, adsorption, and dilution. Prior to an analysis of precipitation, some of the complexities involved with metals in aqueous solutions should be understood. Metals in solution may exist as dissolved ionic species and organic and inorganic complexes. Metal cations in water are hydrated and will form aquo complexes [Stumm 1970]. The exact form of the complex is a function of pH, concentration of the specific cation and other metallic species present, and the redox potential. Metals may also form complexes with organic and inorganic substances. The resultant complex may or may not be in the ionic form. For example, a copper ion may react with ammonia forming a complex ion as shown in the following reaction.

$$Cu^{+2} + 4NH_3 \longrightarrow [CU(NH_3)_4]^2 \qquad (10)$$

Metallic ions may also complex with ligands forming complex molecules which may be difficult to remove from solution. The presence of these complex forms, in waters affected by mine drainage is not known. Wentz suggested that a significant quantity of metals may be transported by the suspended load. It is further stated that the metals may be: 1) adsorbed onto solids including colloids; 2) contained in coatings on sediment grains (precipitates and coprecipitates); 3) incorporated into solid biologic materials; 4) incorporated in crystalline structures and complexed with organics not in solution (chelation) [USGS 1974a]. It is unclear how much this complexing phenomenon affects metal ion mobility, also it is unknown what percentage of the suspended metal is carried in each of the above forms. The most mobile fraction of the total metallic load in a stream is the dissolved fraction which is Eh-pH dependent.

The total concentration of cadmium, in Kerber Creek, is shown in Figure 12. The cadmium concentration appears to be inversely proportional to pH. The pH slowly increases downstream from the mine discharge and as this occurs, the solubilities of the dissolved metals is decreased. At the point when the solubility of a specific metal is exceeded, the metal will no longer be dissolved but will be in the suspended form and may or may not be removed from solution.

The dissolved concentration of zinc is shown in Figure 13 and the dissolved fraction of the total metal loads along the stream is shown in Figure 14. It can be seen by comparing these figures that the total metal concentration and the dissolved fraction are decreasing downstream. This is consistent with the above theory.

Jenne proposed that the sorption of heavy metals occurs in response to the following factors: 1) aqueous concentration of the metal in question; 2) aqueous concentrations of other heavy metals; 3) pH; 4) amount and strength of organic chelates and complex ion form present. It was suggested that other controls are: 1) organic matter; 2) clays; 3) carbonates; 4) precipitation as oxides or hydroxide [Jenne 1968].

Ferric hydroxide is a very insoluble precipitate which forms a reddish-yellow gelatinous floc, also known as yellow-boy. Some researchers suggest that metals will adsorb onto this precipitate and be removed from solution [Jenne 1968]. Wentz observed that adsorption of metal onto ferric hydroxide was of minor importance in Kerber Creek during high flows [USGS 1974a]. This is understandable as stream velocities during peak flows are much higher than during low flow periods. Possibly metals precipitate and settle to the stream bottom during low flow periods only to be scoured and redeposited downstream during higher flow periods.

The presence of colloidal materials such as ferric hydroxide or clay particles may enhance the mobility of the less mobile metals. Wentz suggested that clay minerals may adsorb metals and transport them downstream where flocculation and settling may take place [USGS 1974a]. In other words, stream velocity, (energy) is an important parameter in the mobility of metals. This can be seen by comparing metals concentrations with the stream gradient in Kerber Creek Figure 15. Thus, the ultimate sink for metals may be quiescent streams or lakes far downstream from the main section of the polluted stream.

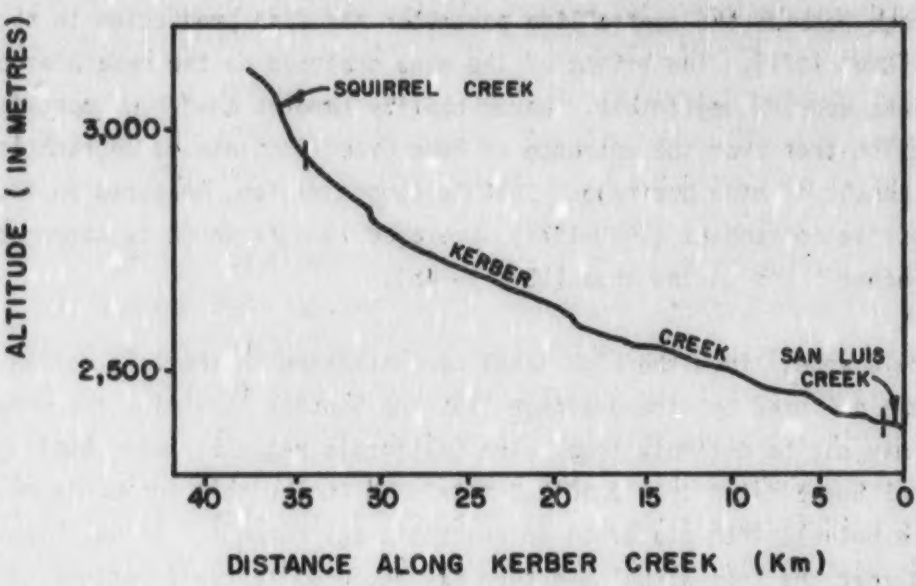


Figure 15. Gradient of Kerber Creek.

Lakes as Sinks for Metals

Several lakes in the western United States are fed by streams polluted by mine drainage. Lake Chelan in Washington, Lakes Shasta, Berryessa and Nacimiento, and Comanche Reservoirs in California, Lynx and Patagonia Lakes in Arizona, Dillon Reservoir in Colorado, and Coeur d'Alene Lake in Idaho are a few of the lakes so affected.

The effects to these lakes vary and undoubtedly the extent of pollution is a function of the mass inflow of pollutants, the natural buffering capacity of the lake waters and the hydraulic detention time of the lake. In large lakes, the effects of mine drainage may be the most notable at the mouth of the polluted stream. For instance at Lake Berryessa, California, the best spawning gravels, are at the mouth of

Pope Creek which is polluted by mine drainage. Therefore the mine drainage becomes the controlling parameter for fish production in the lake [CRWQ 1971]. The effect of the mine drainage on the remainder of the lake appears negligible. Water quality samples measured approximately ten kilometres from the entrance of Pope Creek indicate no degradation as a result of mine drainage. Sulfate concentration, measured in four successive Septembers (1968-1971), averaged 19 mg/1 which is comparable with other lakes in the area [USGS 1974b].

It would appear from the high metal concentration in the lake deltas of streams polluted by mine drainage that the benthos is a sink for metals. This may not be entirely true. The California Regional Water Quality Control Board noted that oxidized metals in the benthic sediments may become soluble when placed in an anaerobic environment. It was hypothesized that the semi-annual overturn may recirculate toxic benthic waters. The discharge of these bottom waters has been observed to have a detrimental effect on the fishery downstream from Comanche Reservoir [CRWQ 1971].

Anaerobic action may not alone be the source of this redissolution of metals. Stratification of pH is known to exist. Smith, and others observed variations in pH in a strip mine lake of over two pH units [EPA 1971c]. This would affect the concentration of metals as solubility of metal ions changes by orders of magnitude with a change of pH units (see Figure 4).

Another possible cause of this redissolution is that organic concentrations are higher in lakes than streams, increasing the possibility of ligand formation. Jenne noted that the range of dissolved organic carbon in large streams in the northwestern United States was between 3 and 7.7 mg/1 while lakes were noted to contain between 27 and 29 mg/1 [Jenne 1968]. The various mechanisms involved are not yet fully known and are recommended for further study.

The Effects of Mine Drainage on Groundwater

There has been much data written on the effects of mine drainage on surface waters but little data is available on groundwater pollution. The potential for groundwater pollution exists at the mine, tailings, or waste pile. Water may pass through a mine, react with exposed elements, and enter the groundwater basin. Tailings or waste piles also offer a potential source of groundwater contamination. Prior to 1920, milling operations produced coarser, more permeable tailings than present day methods. The porosity of modern tailings may be limited due to very fine grinding and stratification upon deposition which limits the flow of water through the pile.

Preliminary findings from studies in Tucson, Arizona have indicated that tailings water has been identified down to a depth of approximately 30 metres [Personal Communications with Donald R. Anderson, Professor of Environmental Engineering, Loyola Marymount University, California]. Groundwater in this area is at a depth of approximately 75 metres and although its quality is similar to that of tailings water, it has not been conclusively determined that the groundwater has been adversely affected by the tailings.

The Cataldo Mission Flats area near Coeur d'Alene, Idaho is a large area of dredge deposit. The majority of these deposits are jig tailings which were discharged directly into the river during mining operations and subsequently dredged to enable paddle boats to navigate the river [Galbraith 1972]. Many investigators have studied the problem and have discovered that groundwater has been degraded by low pH and high metals concentrations. Norbeck, et al, found that when groundwater is exposed to the old tailings, bacteriological and chemical leaching may occur [American Water Resources Association 1974].

It was noticed that below one settling pond, pH decreased from a value of 6.0 to a low of 4.3, 3,700 metres downgradient. Concentrations for cadmium, lead, and zinc were measured at 0.3 mg/l, 0.9 mg/l, and 33.0 mg/l respectively. These concentrations are extremely high and would render the water unfit for human consumption.

It appears from the Cataldo Mission Flats data that the pollutants associated with mine drainage are fairly mobile in an afuifer. Little other data was found to support this conclusion and it is recommended that this subject be studied in greater detail.

TOXICITIES AND BIOLOGICAL EFFECTS OF POLLUTANTS

Many of the constituents of mine drainage are common to natural waters in low concentrations. Many trace elements are essential, in small quantities, to life while others such as arsenic and cadmium have no known biological function. Conversely, all trace elements can be toxic in high enough concentrations. The term toxic may easily cause confusion as it is a relative term. Toxicities may mean anything from a slight discomfort to death; also reactions may be an acute (immediate) or chronic (gradual).

Many ions exhibit antagonistic (decreased) and synergistic (increased) effects on toxicities. Associated differences in physiology, such as life-cycle and species, can also have a considerable effect on the response of an organism to trace element concentrations. An example of the effect on life-cycle can be seen in Lynx Lake, Arizona (AZ-1) where the metal concentrations appear to limit fish propagation and growth.

A classic example of the differing effect between species is the lower toxicity threshold for zinc and copper to fish than humans. Due to the variabilities of toxicities and effects to plant, animal, and man, the following sections will cite examples of these variabilities in toxicities and the effects to aquatic life, agricultural and municipal users. Much of the data presented is summarized from McKee and Wolf and will not be referenced each time unless another source is used [CWRCB 1963]. This discussion is presented to illustrate examples of toxicity and other adverse effects of mine drainage and is not meant to propose water quality standards.

AQUATIC LIFE

Aquatic life has been listed first since it has undoubtedly suffered the greatest impact from mine drainage. The aquatic eco-system has suffered a wide range of various environmental stresses from limited diversity to stream sterility. Toxicities of metals and acids are not the sole cause of the stress. For instance, vast quantities of sludge produced by the precipitation of ferric hydroxide coats rocks and smothers valuable spawning gravels.

Bottom dwelling invertebrates usually have rather long (1 to 3 years) and complex life histories. They are relatively immobile and cannot quickly avoid harmful changes in their environment. Their presence, absence, or abundance tends to reflect the recent history of the environment. Among these benthic organisms there is a wide range of tolerance to different environmental stresses. Therefore, the community structure may show marked changes in species composition. The evaluation of the community structure of benthic organisms and the degree of pollution present at a specific location, can be facilitated by comparison of diversity index values [Missouri Department of Conservation 1974].

The effects of harmful substances upon fish life vary with species, size, age, and physiological conditions of the individuals. Water favorable for some species may not necessarily be adequate for others that have adapted to somewhat different conditions. For instance, toxicants in low concentrations may have no apparent effect upon a fish species but may limit the diversity of the food organisms available; thus, limiting the overall population of the fish.

The effects of deleterious substances upon fish vary with the physical and chemical composition of the water supply. The interrelationships of the antagonistic and synergistic effects of the dissolved constituents of a specific water are extremely important. Hardness is known to be antagonistic toward the toxicity of cadmium, chromium, cobalt, copper, lead, molybdenum, nickel, vandium, and zinc to fish and other aquatic life. Conversely, cadmium, copper, and zinc are synergistic in their effect on fish.

Toxicities of Dissolved Constituents to Selected Fish Species

The following is a listing of several metals and compounds associated with mining activities and their toxic effects on selected fish species.

Aluminum

The hydroxides and carbonates of aluminum are very insoluble and are not to be expected in sufficient quantities at normal pH range. The solubility increases as the pH is reduced (see Figure 4). Concentrations of between 0.07 to 5.0 mg/l have been reported to be toxic to various fish species.

Arsenic

Concentrations as low as one milligram per litre have been reported toxic to certain fish species.

Barium

Like aluminum, the carbonates and sulfate forms are very insoluble and are not to be expected in significant quantities in mine drainage.

Cadmium

Most of the quantitative data on toxicity of cadmium toward fish and other aquatic organisms are given under the specific cadmium salt, expressed as cadmium. These data indicate that the lethal concentration for fish vary from about 0.01 to 10 milligrams per litre, depending on the test species, temperature, and time of exposure. Cadmium acts synergistically with other substances to increase toxicity. Cadmium concentrations of 0.03 milligrams per litre in combination with .15 milligram per litre of zinc cause mortality of salmon fry.

Copper

Toxicity of copper to aquatic organisms varies significantly with species and also with the physical and chemical characteristics of the water, such as temperature, hardness, turbidity, and acidity. In hard water the toxicity of copper is reduced by the precipitation of copper carbonate or other insoluble compounds. In soft water concentrations of between 0.015 to 3.0 milligrams per litre have been reported as toxic. Also in soft water copper is known to be synergistic with zinc. As hardness increases, this synergism apparently disapears. Other investigators have reported that under certain conditions concentrations of copper can be toxic to trout at 0.08 micrograms per litre.

Cyanide

Toxicity of cyanide may vary markedly with pH. It has been reported that pH between the ranges of 6.0 to 8.5 had little effect on the toxicity.

In natural streams, cyanides deteriorate or are decomposed by bacterial action so that excessive concentrations may be expected to diminish with time. The presence of organic matter appears to lessen the time necessary for removal. In addition to pH the toxicity toward fish is affected by temperature, dissolved oxygen, and concentration of other minerals. For instance, a rise of 10 degrees centigrade was known to produce a two to three-fold increase in the rate of lethal action. Concentrations of between 0.05 to 10 milligrams per litre have been reported to be toxic to various species of fish.

Iron

The deposition of ferric hydroxide on the gills of fish may cause an irritation and blocking of the respiratory canals. In addition, precipitates of ferric hydroxide may smother fish eggs and disturb the benthic community. Toxicity of iron appears to be a function of its oxidation state and whether or not it is dissolved or suspended. Concentrations of iron of between 0.2 to 50 milligrams per litre have been shown to be toxic to various fish species.

Lead

Excess concentrations of lead in water apparently suffocate fish due to a destructive layer that is formed as a result of a reaction between lead and organic constituents of mucous. Hardness is antagonistic to the toxicity of lead. Lethal or toxic concentration of lead to various fish species have been reported at between 0.1 to over 60 milligrams per litre.

Manganese

Manganese has a limited toxicity toward fish and appears to be somewhat antagonistic toward the toxicity of nickel. Concentrations of 1.0 to 2,700 mg/l have been reported to be toxic to various fish species.

Mercury

Elemental mercury is very insoluble in an aqueous environment. Generally in surface waters, mercury compounds are rapidly removed from solution and adsorbed or concentrated in suspended particulate matter, organic materials such as algae and stream and lake sediments. After removal from solution inorganic mercury can be converted to organic forms by methanogenic bacteria as well as by nonenzymatic reactions that are usually encountered under anaerobic conditions. Methylated mercury compounds are readily assimilated by aquatic organisms and bioaccumulation of mercury is an important consideration to the higher trophic levels in a food chain. Studies have shown concentration factors (ratio of mercury in an organism to that in the water) of 250 to 3,000 in algae and 1,000 to 10,000 in ocean fish. Concentrations of 0.004 to 0.02 milligrams per litre have been reported harmful to acquatic organisms [CWCB 1974, EPA 1971m, CWRCB 1963, Hines 1971, EPA 1974g].

Molybdenum

Molybdenum does not appear to be extremely toxic to fish. A 96-hour TL_{50} of molybdic anhydride to the fathead minnow in soft water was found to 70 milligrams per litre. Hardness exhibited an antagonistic effect toward this toxicity.

Nickel

Copper, zinc, and iron appear to be more toxic to fish than nickel, however, concentrations of nickel as low as 0.8 mg/l have been reported to be toxic.

Selenium

Selenium is an analogous to sulfur in many of its chemical combinations. In nature, selenium occurs in some soils as basic ferric selenate, as calcium selenate, and as elemental selenium. Minute concentrations of selenium do not appear to be harmful to fish during the exposure period of several days. However, constant exposure to traces of selenium have caused disturbances of appetite, equilibrium, pathological changes, and in a few cases, death after several weeks. Selenium may be passed through various trophic levels to the fish and accumulate in liver in lethal doses. Toxicities of selenium have been reported at 2.0 milligrams per litre.

Silver

Silver is reportedly extremely toxic to fish. As little as 0.003 milligrams is known to have been toxic to some species. A higher level of toxicity was found at 0.2 milligrams per litre for other species.

Sulfate

In the United States waters that support good game fish, 5 percent of the waters contain less than 11 milligrams per litre of Sulfate, 50 percent less than 32 milligrams per litre, and 95 percent less that 90 milligram per litre. Water containing less than 0.5 milligrams per litre of sulfate will not support growth of algae.

Zinc

The sensitivity of fish to zinc varies by species, age, condition of the fish as well as with physical and chemical characteristics of the water. Some acclimatization to the presence of zinc is possible. Survivors of batches subjected to dissolved zinc have been less susceptible to additional zinc concentrations than fish not previously exposed. Copper has exhibited a synergistic effect to the toxicity of zinc. In soft water concentrations of zinc ranging from .1 to 1.0 milligrams per litre have been reported to be lethal. Calcium is antagonistic towards such toxicity.

MUNICIPAL AND AGRICULTURAL USES

High concentrations of heavy metals in municipal and agricultural supply waters may have long range detrimental effects. Wildlife and grazing animals normally drink from surface water sources and ingest both dissolved and suspended matter.

If a surface source is used for domestic supply, the water usually is flocculated, settled, and filtered. If metals are not removed sufficiently by standard unit operations additional processes must be used for metal removal, thus increasing the cost of treatment. The use of polluted waters may also be limited for irrigation as many plants are sensitive to certain metal ions.

A comparison of various drinking water standards and effluent limitation guidelines for the ore mining industry is shown in Table 9. The effects of selected metals on municipal and agricultural uses are discussed further.

TABLE 9. COMPARISON OF DRINKING WATER STANDARDS AND EFFLUENT LIMITATIONS SELECTED DRINKING WATER STANDARDS [a]

Water-Quality Parameter	Interim National Primary Drinking Water Regulations[b]	U.S. Public Health Service (1970)	World Health Organization 1961 European Standards [c]	Interim Effluent Guidelines Ore Mining Industry [d]
Aluminum	---	---	---	1,200[e]
Arsenic	50	50,10[f]	200[f]	1,000[g]
Barium	1,000	1,000	---	---
Cadmium	50	10	50	100
Chromium(VI)	---	50	50	---
Copper	---	1,000	3,000	1,000
Cyanide	---	200,10[f]	10	20
Fluoride	---[h]	[d]	1,500[f]	
Iron	---	300[f]	100[f]	1,000[e]
Lead	50	50	100	400
Manganese	---	50[f]	100[f]	
Mercury	2	5	---	2
Selenium	10	10	50[a]	
Silver	50	50	---	
Uranium	---	---	---	4,000[i]
Zinc	---	5,000[f]	5,000[f]	400-1,000
pH	---	---	---	6.0-9.0

[a] Maximum daily concentrations in micrograms per litre.
[b] Reference [EPA 1975g].
[c] Reference CWRCB 1963].
[d] Base and precious metal subcategory unless otherwise stated [EPA 1975h].
[e] Bauxite ore subcategory.
[f] Recommended limit.
[g] Feralloy ore subcategory.
[h] Limit varies inversely with average annual maximum daily air temp.
[i] Uranium ore subcategory.

Municipal and Agricultural Effects

The following is a listing of several compounds associated with mine drainage and their affects on municipal and agricultural uses of waters.

Aluminum

Concentrations of aluminum of 1.0 to 14 milligrams per litre have been noted to be injurious to various crop types. Little effect was noted for stock and wildlife watering.

Arsenic

Concentrations of arsenic of one milligram per litre have been shown to be injurious to certain plant species. It is believed that the lethal dose of arsenic for animals is approximately 20 milligrams per pound of animal.

Cadmium

Cadmium tends to concentrate in liver, kidneys, pancreas, and thyroid of animals. Once it enters the body it is likely to remain. Doses of cadmium to dogs are poisonous between 0.15 to 0.3 grams per kilogram of body weight.

Copper

Small quantities of copper are essential for plant growth. Concentrations of 0.2 milligrams per litre have been shown to be toxic to certain plant species. It has been reported that among cattle toxicity develops at 2 grams of copper sulfate per kilogram of live-weight per day. Chronic poisoning of sheep has been caused by 1.5 grams of copper sulfate daily for 30 to 80 days.

Cyanide

The toxicity of the cyanide in the hydrogen-cyanide form range from between 0.03 grams for dogs to between 0.39 and 0.92 grams for cows. No deleterious effects are expected as a result of cyanide in irrigation water as cyanide is quickly complexed with organic matter and is no longer toxic.

Iron

Iron is apparently of little importance in irrigation practices in the form usually occurring in irrigation water. It is an essential constituent in animal diets but if the water is high in iron, cattle will not drink sufficient quantities for it to be toxic to their systems.

Lead

Inorganic lead salts in irrigation waters may be toxic to plants. Farm animals have been known to have been poisoned by lead in the drinking water regardless of whether or not it is in solution or suspension. Chronic lead poisoning among animals has been caused by 0.18 milligrams per litre of lead in soft water.

Manganese

Manganese is essential for plant growth. Manganese in concentrations of 0.5 to 500 milligrams per litre have been reported to be toxic to varying plant species. It is also essential in the diet of animals. Manganese has been fed to cattle in dosages of 50 to 600 milligrams per kilogram of baby weight for 20 to 45 days without serious effects.

Molybdenum

Low concentrations of molybdenum are essential for the healthy growth of various plants. Like many of the other trace elements, excess concentrations are toxic. Concentrations of between 0.5 to 200 milligrams per litre have been shown to have injurious effects on the growth of various crops. Molybdenum also appears to be an essential trace element for some animals. Copper appears to be antagonistic towards the toxicity of molybdenum. Molybdenum has been observed to concentrate in the foliage in pastures and cases have been noted where cattle, feeding on foliage in pastures so affected, have shown symptoms of molybdenum toxicity.

Nickel

Nickel is extremely toxic to some plant species such as citrus and beans. Lethal doses for dogs range between 10 to 20 milligrams per kilogram of body weight.

Selenium

Plants appear to vary in their ability to absorb selenium. Concentrations in the plants may be determined by many factors such as species and the age of the plant, season, concentration of the soluble selenium compounds in the root zone. Plants can adsorb large amounts of selenium from irrigation water with no apparent injurious effects. Selenium poisoning in wildlife, known as alkali disease or blind staggers, frequently occurs among livestock of the great plains region.

Sulfate

Sulfates are slightly more toxic than chlorides in irrigation water. High concentrations of sulfate may cause precipitation of calcium. Generally it is agreed that excellent irrigation water contains less that 190 milligrams per litre of sulfate. Sulfate appears to exhibit an antagonistic effect towards the toxicity of selenium in cattle. High concentrations, in excess of 2,500 milligrams per litre have shown to cause a cathartic action in dogs.

Zinc

Small quantities of zinc are necessary for nutrition in most crops, however, toxicity results from concentrations exceeding low levels. Zinc concentrations of between 3.0 and 10 milligrams per litre have been shown to be toxic to various plant species.

SECTION 6

ASSESSMENT OF MINE RELATED WATER POLLUTION

Many federal, state and local agencies are aware of water pollution problems associated with inactive mining activities within their area of responsibility. An objective of this study has been to collect and compile this data from these sources. The results of this compilation are presented in this section and Appendix D.

DATA COLLECTION PROCEDURE

All state agencies responsible for water pollution control were contacted to determine their knowledge of inactive mine pollution and data available. Where a significant problem in mine related pollution occurred, members of the investigating team visited the agencies to review their files. To augment this data, regional offices of the U.S. Bureau of Land Management, U.S. Bureau of Mines, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, U.S. Forestry Service, U.S. Geological Survey, and U.S. National Park Service were contacted. Many of the regional directors of these agencies referred the request for information to their local subordinant office which often responded with detailed data which complimented the data collection from the state agencies.

NATIONAL SUMMARY

The summary presented in this section and in Appendix D is a compilation of data collected from all of the responding agencies contacted. It is recognized that many of the states have concentrated their pollution control efforts toward identifying and correcting point source pollution and have not had the budget or manpower to perform a detailed analysis of problems such as these associated with inactive mines. It was observed during the course of the study that in many areas that the level of detail in problem identification was proportional to the severity of the problem. Many non-point sources of low level pollution from mining activities are undoubtedly undocumented, therefore, this study is limited in scope in many areas to a summary of information collected on only the most severe problems. The study, therefore, should be used as a broad-based planning guide and should not be interpreted an assessment with a sufficient level of detail for use on a localized basis.

The results of this study indicate that pollution from inactive mines at approximately 100 locations throughout the county has affected a total of 1,200 kilometres of streams and rivers. This pollution is characterized by acid, heavy metals, and increased sedimentation. As discussed in Section 5, the acid and metals are, for the most part, produced by the oxidation of base metal sulfides. It is estimated that the inactive mines are discharging between 30,000 and 50,000 metric tons of acid and 10,000 metric tons of metals annually.

Sediment problems may be increased in a watershed where mining has occurred. Banks left in an unstable condition can be washed out during periods of high flow; unvegetated slopes are more susceptable to erosion; and tailings may have been carelessly deposited directly in the streambed. Due to the complex relationships of soil stability and local storm events, it is impossible to quantify the sedimentation produced by sudden washouts and slope failures. The variabilities involved in continual erosion make prediction of sediment produced on a national basis impractical. Prediction of sediment on a specific watershed may be possible and is discussed in greater detail later in this section. Thus, the national assessment notes those areas where increased sedimentation is thought to be a problem related to inactive mines.

REGIONS EXHIBITING MAJOR IMPACT

The specific location of all areas with known pollution from inactive mines is shown on Figure 1. Detailed information on each of the areas, as well as the estimated pollutant loading for acid and heavy metals for each area is presented in Appendix D.

Eighty percent of the water pollution resulting from inactive mines has occurred in the following four areas:

- California
- Idaho-Montana
- Colorado
- Missouri

Less severe pollution has been reported in other scattered areas throughout the country. The following discussion will summarize the major impacts to these four areas.

California

Approximately 89 kilometres of streams have been polluted by drainage from mining activities in eight different areas in the state. Inactive copper, gold, and mercury mines located in the Sierra Nevada Mountains and the Coastal Range are the principal sources of pollution. The Leviathan Mine (CA-4) and the Shasta District (CA-8) have been studied in considerable detail. In a few cases, the state has taken the owners of mines to court in an attempt to get the owners to control the pollution. These law suits are being prosecuted at the time of this writing.

Attempts have been made at three areas to reduce or eliminate the discharge of pollutants with marginal success. Abatement schemes include diversion of drainage to evaporation ponds and installation of a clay blanket on a tailing to prevent water infiltration.

Idaho-Montana

In Idaho in excess of 130 kilometres of streams have been polluted by discharges from both active and inactive mining. The problem areas are located in three areas of the state: 1) Coeur d'Alene; 2) Central Idaho; 3) Southeastern Idaho. Base metals, precious metals, and phosphate are the principal minerals mined in the affected areas. In the Coeur d'Alene area, an inseparable combination of active and inactive operations for antimony, lead, and zinc have eliminated fish life in approximately 55 kilometres of the South Fork of the Coeur d'Alene River. In central Idaho, drainage from the Blackbird Mine, an inactive cobalt mine, has polluted 50 kilometres of Panther Creek with acid and heavy metals. The southeastern part of the state is the center of large active phosphate mining activities. Some inactive sites in this area have caused increased sedimentation in the streams from erosion of the phosphate slimes. No estimate was available of the length of stream effected.

In Montana fourteen mines or mining districts have affected the water quality of approximately 160 kilometres of stream. Approximately 56 kilometres of stream have been polluted by erosion of tailings from inactive placer gold-mining operations. The remainder of the problems are acid and metals from inactive base and precious metal mining activities.

Colorado

In excess of 675 kilometres of streams in the state have been polluted by both active and inactive mining activities. Wentz and others have extensively studied these areas but it is impractical to attempt to separate the effects of the active and inactive mines in many areas [EPA 1973j, USGS 1971m]. The principal problems are acid and metals from base and precious metal mining areas. The Idaho Springs-Central City (CO-2,3,4) and the Leadville (CO-6) areas account for about one-third of the state's total length of polluted streams.

Missouri

Heavy metals and sediment from inactive barite and zinc mining operations have polluted approximately 135 kilometres of streams. The state's major problem area is the Flat River-Bonne Terre lead mining district where 64 kilometres of stream have been polluted from the erosion of tailings deposited in the streams. Heavy metals are being leached from the sediments into the streams greatly limiting fish life.

METHODOLOGY OF ASSESSMENT

A variety of state and federal agencies have conducted studies on many of the major problem areas in the country. Areas such as Spring Creek (CA-8), Idaho Springs-Central City (CO-2), Blackbird (ID-1), Bunker Hills (ID-3), Hughesville (MT-1), and Contrary Creek (VA-1) have been the subject of extensive studies. In some areas quantitative and qualitative measurements were conducted throughout the year or over a period of many years, enabling an accurate determination of the annual pollutant loading. In other areas biological testing, including aquatic and benthic diversity sampling, has been conducted to determine the length of stream system affected by mine drainage. However, the testing criteria used by the agencies varied. Often the tests were run to perform a single purpose function such as a determination of the toxicity of the waters to fish. The objectives were rarely an estimation of the annual pollutant loading.

The constituents most frequently present in mine drainage are acid, copper, iron, manganese, zinc, and sulfate. It was decided to estimate the annual pollutant loading based on these constituents but there was some difficulty due to the varied testing criteria used by different agencies. Acid cannot be determined directly as it begins interaction with its environment upon formation. Hence, acid must be measured indirectly by measuring the anion that was associated with its formation.

In the case of mine drainage that anion is sulfate which is also the most conservative of the constituents in an aquatic environment. Unfortunately, it is one of the less frequently measured ions since it is not toxic and rarely causes problems.

Water quality measurements were reported at approximately 50 percent of the problem areas. Of these, one or more of the desired constituents were unreported at approximately 40 areas. Therefore in order to determine the annual pollutant loading, it was necessary to synthesize data for these unreported constituents. The methodology used in this synthesis and pollutant loading calculation will be discussed further.

Heavy Metals and Sulfate Loading

In order to calculate the pollutant loading using the available data, it was necessary to first estimate concentrations of ions not measured. Twenty-two mine drainage analyses were selected from approximately fifty problem areas where analyses were available. The analyses were selected based on the following criteria: 1) analyses with extremely high or low concentrations were excluded; 2) all analyses which included sulfate measurements were included; 3) other relatively complete analyses were included. The constituents of these twenty-two analyses were averaged to provide a representation of a typical mine drainage water. Relationships between the various ions were then determined by computing their relative concentrations as a ratio such as $\frac{Cu}{Fe}$, $\frac{Fe}{Mn}$, and $\frac{Zn}{SO_4}$. These ratios are shown in Table 10 as $\frac{X}{Fe}$, $\frac{X}{Cu}$, etc. The average concentrations and the number of times each ion was measured in the twenty-two analyses are also shown.

TABLE 10. EMPIRICAL RELATIONSHIP BETWEEN CONSTITUENTS OF MINE DRAINAGE

Constituent (X)	Average Concentration mg/l	Number of Analyses [a]	Ratio				
			$\frac{X}{Fe}$[b]	$\frac{X}{Cu}$	$\frac{X}{Zn}$	$\frac{X}{Mn}$	$\frac{X}{SO_4}$
Iron	180	21	1	4.94	2.91	2.55	0.10
Copper	37	18	0.20	1	0.59	0.52	0.02
Zinc	62	15	0.34	1.70	1	0.88	0.03
Manganese	71	12	0.39	1.93	1.14	1	0.04
Sulfate	1880	15	10.45	51.57	30.41	26.66	1

[a] Number of times constituent measured out of the 22 analyses used.

[b] X represents the constituents mentioned in the first column.

The probable pollutant concentrations were calculated for all problem areas with incomplete data using the ratios shown in Table 10 and the known data at each area. The specific ratio used to calculate the unknown data was selected in the order given in the table since it is desirable to use the ratio that was based on the greatest number of analyses. For instance, if an analysis contained only iron and zinc data the unknown concentrations were calculated by multiplying the known iron concentration by the appropriate unknown to iron ratio $(\frac{X}{Fe})$. If iron were unknown, the appropriate set of ratios would be selected by using the next available ratio (i.e., $\frac{X}{Cu}$, $\frac{X}{Mn}$, $\frac{X}{Zn}$, and $\frac{X}{SO_4}$ in order).

As an example, assume the following analysis:

Cu = 75 mg/l
Zn = 120 mg/l

The unknown iron, manganese, and zinc concentrations would be determined using the known copper concentration as follows:

$$\text{Iron} = 75\ (\text{Cu-mg/l}) \times 4.94\ \left(\frac{X}{Cu}\right) = 371\ \text{mg/l Fe}$$

$$\text{Manganese} = 75\ (\text{Cu-mg/l}) \times 1.70\ \left(\frac{X}{Cu}\right) = 128\ \text{mg/l Mn}$$

$$\text{Sulfate} = 75\ (\text{Cu-mg/l}) \times 51.57\ \left(\frac{X}{Cu}\right) = 3880\ \text{mg/l}\ SO_4$$

The pollutant concentrations were calculated for all problem areas where at least one pollutant concentration was known. The pollutant loadings were calculated by multiplying this pollutant concentration by a known or estimated annual flow rate. A summary of the loadings is shown in Table 11. The loadings, flow rates, and other pertinent data for each problem area are shown in Appendix D after the state summaries.

TABLE 11. SUMMARY OF ESTIMATED ANNUAL LOADING FOR METALS AND ACID [a]

State	Acidity As $CaCO_3$	Iron	Copper	Manganese	Zinc	Sulfate
California	20,640	1,890	90	230	460	5,670
Colorado	10,900	1,000	35	350	1,410	10,420
Idaho	330	30	7	12	1,310	320
Missouri	75	7	1	13	220	75
Montana	3,175	385	165	65	570	5,530
Nevada	320	30	2	12	10	309
New Hampshire	--	2	1	--	23	--
New York	870	90	--	--	--	330
Oregon	2,145	195	--	7	1	2,020
Vermont	1,030	290	1	--	1	--
Virginia	7,210	665	8	40	25	2,660
Washington	60	5	4	1	30	55
TOTAL	47,773	4,591	314	1,044	4,060	30,181

[a] Metric tons per year.

Acid Loading

Acid is produced by the oxidation of many base metal sulfides but as previously discussed, the predominant source of acid is pyrite. For the purposes of calculating acid loading, it was assumed that all acid is formed by pyrite oxidation, shown by Reaction 5 (see Section 5).

It can be seen from this reaction that the oxidation of pyrite produces four equivalents of acid and two moles of sulfate. These stoichiometric relationships cannot be used to directly calculate acid for the following reasons: 1) acid and iron are non-conservative in the environment; 2) sulfate concentrations were one of the less frequently measured ions; 3) sulfate may be produced by non-acid forming reactions. Iron was the most frequently measured ion. Therefore, it was decided to calculate sulfate empirically from the iron-sulfate ratio shown in Table 10 and to calculate acid stoichiometrically from that theoretical concentration. The sulfate to acid conversion factor is 1.04 which yields acidity in terms of $CaCO_3$ (mg/l).

The annual acid loadings were calculated by multiplying the calculated acid concentration by a known or estimated flow rate. A summary of acid loading is also shown in Table 11.

The total acid and sulfate loads shown are approximately 47,800 and 30,200 metric tons per year respectively. These figures appear to be in disagreement with the sulfate to acid conversion factor of 1.04. A possible explanation for this difference is that the sulfate load was based on known and synthesized data while the acid load is based on synthesized sulfate data only. Regardless of this difference, the annual acid load may be expected to be between 30,000 and 50,000 metric tons.

Effects of Inactive Mines on Sediment Production

The combination of many factors may contribute to an increased sediment load from a watershed. Tailings may contain a large percentage of fine particles. As shown on Figure 2, the average particle size from a froth flotation mill is approximately 0.04 millimetres. Tailings piles are often steeply sloped, adjacent to streams, and void of vegetation. Erosion of tailings piles often occur because of the failure of mining companies to construct the tailings pond dams that are designed to withstand erosion.

Sediment from tailings may be released into a watercourse either as a continual erosion or sudden bank failure. Bank failures may occur in many ways. For instance, erosion of the toe of a tailings pile may cause a sudden failure of the slope resulting in the discharge of tremendous quantities of mud into a stream. Regardless of the cause of sudden deposition, there is no method to qualitatively or quantitatively predict sediment produced in this manner. Therefore, the remainder of this section will be devoted to the discussion of the sedimentation caused by the continual erosion of tailings.

The impact of continual erosion of mine tailings on the sediment production of a watershed depends as much on watershed characteristics as on the characteristics of the mine tailings. A large watershed with a high natural sediment loading rate will not be significantly impacted from mine tailings while a small watershed with a low natural sediment loading rate may be drastically affected. Natural erosion rates and subsequent sedimentation vary greatly throughout the country and are affected by many factors such as climate, terrain, local soil conditions, and man's activities. Sedimentation from watersheds containing tailings will be affected by other variables such as area of watershed covered by tailings, method of tailings placement, particle size in the tailings, vegetative cover of the tailings, and slope of tailings.

Due to these many variables there is currently no predictive model designed to allow calculation, on a national basis, of the annual sediment produced from inactive tailings. The following discussion presents a technique allowing prediction of tailings-induced sediment on a regional basis. A typical unit sediment load for tailings is developed. This is combined with natural unit sediment loads for the watersheds to form an equation for overall unit sediment load as a function of percent of watershed covered by tailings.

Natural Unit Sediment Loads

Many models have been developed for predicting natural sediment load from watersheds. However, most are not related to the mountainous terrain often encountered in mining activities. The majority of metal mine tailings are in the mountainous regions of the western United States. Flaxman [1972] of the Soil Conservation Service has performed sedimentation studies on several watersheds in eleven western states. His studies included mountainous watersheds ranging in size from a few hectares to over 12,000 hectares. The method presented by Flaxman is adaptable to assessment of potential sedimentation problems from the erosion of mine tailings.

In Flaxman's studies, sediment yields were measured for each watershed. Four independent variables were developed to describe the watershed characteristics. A multiple linear regression analysis was applied to the independent variables (X_1-X_4) and the dependent variable (Y=sediment yield) to develop an equation for the prediction of sediment yields.

The resulting equation is:

$$\log (Y+100) = 6.213 - 2.191 \log (X_1+100) + 0.060 \log (X_2+100) \qquad (11)$$

$$-0.0164 \log (X_3+100) + 0.0435 \log (X_4+100)$$

Where:

Y = annual sediment load (ac-ft/sq mi)

$X_1 = \frac{\text{Precipitation}}{\text{Temperature}} \quad \left(\frac{\text{inches per year}}{°\text{F}}\right)$

X_2 = Weighted average slope of watershed

X_3 = Percent soil particles coarser than one millimetre (in the upper five centimetres of the soil profile)

X_4 = Aggregation dispersion characteristics (percent of soils particles finer than two microns in the upper five centimetres of the soil profile)

The variables in equation 11 are expressed in English units, since conversion of the equation into metric units would complicate it greatly.

Variable X_1 is intended as an indirect expression of the natural response of vegetation to climate. It was assumed that there would be more vegetation cover for greater values of this ratio. In areas disturbed by man, such as tailings, this value is set equal to zero.

Variable X_2 is the weighted average slope of the watershed. The variable is calculated by measuring the area between equally spaced contour intervals. Each of these areas is multiplied by the distance between the contour intervals. The summation of the products of this multiplication are then divided by the total watershed area. The resulting answer is expressed as a percent.

Variable X_3 is the percent of coarse particles (greater than one millimetre). This variable is intended to reflect the resistance of coarse particles to erosion.

Variable X_4 is an indication of the aggregation or dispersion characteristics of the soil. Results of field observations by Flaxman indicated that soils that aggregate resist erosion whereas soils that disperse are easily erodible. The pH of a soil is used as a means of classifying the soil. Soils with high pH (greater than 7) are generally associated with low precipitation and sparse vegetative cover and are easily eroded. Soils with low pH (less than 7) are usually associated with higher precipitation and more plentiful vegetative cover. This results in a higher organic content and a low exchangeable sodium percentage which usually is indicative of a more aggregated soil. The sign convention used for this variable indicates the pH of the soil. Soils with a pH less than or equal to 7 were assigned a negative value. Soils with a pH greater than 7 were assigned a positive value.

Two Colorado watersheds were selected from Flaxman's study which had greatly varying natural sediment yields. A method of predicting the effect of mine related sedimentation will be developed for these two watersheds. The watersheds are the Round Butte Reservoir watershed on the eastern slope of the Rocky Mountains and Badger Wash No. 2B on the western slope. The measured sediment yields for these watersheds were 0.33 and 11.00 cubic metres/hectare respectively. The yields predicted by equation 11 are 0.16 and 9.04 cubic metres/hectare respectively. The difference between these measured and computed values was expressed as a ratio and used to correct the unit sediment load for tailings.

Unit Sediment Load From Tailings

In order to predict the unit sediment load produced by tailings it was necessary to modify the independent variables in equation 11. The value for X_1 was set equal to zero to account for the lack of vegetation. The average slope (X_2) of the tailings was assumed to be 30 percent. The value for X_3 was set equal to five percent; this was based on an average of the two curves shown in Figure 2. The value for X_4 was set equal to zero to account for the lack of soil particles less than 2 microns (see Figure 2).

The unit sediment load was calculated for the theoretical watershed completed covered by tailings and adjusted by an average of the correction factors developed for the two example watersheds. This resulted in a sediment yield of 18.4 cubic metres per hectare for the tailings covered watershed.

Effect of Mine Tailings on Natural Sediment Load

The theoretical impact of mine tailings on the two natural sediment loads was determined by a weighted average of the appropriate unit loads.

This was accomplished by the following equation:

$$Y = Y_N + \frac{P_T(Y_T - Y_N)}{100} \qquad (12)$$

Where:

Y = Total unit sediment load
Y_N = Natural unit sediment load
Y_T = Tailings unit sediment load
P_T = Percent of watershed covered by tailings

Estimated sediment loads are plotted as a function of the percent of watershed covered by tailings and are shown in Figure 16 for the Badger Wash and Round Butte watersheds. As expected, it can be seen that tailings induced sediment is more severe in a watershed with a low natural sediment load than in a watershed with a high natural sediment load.

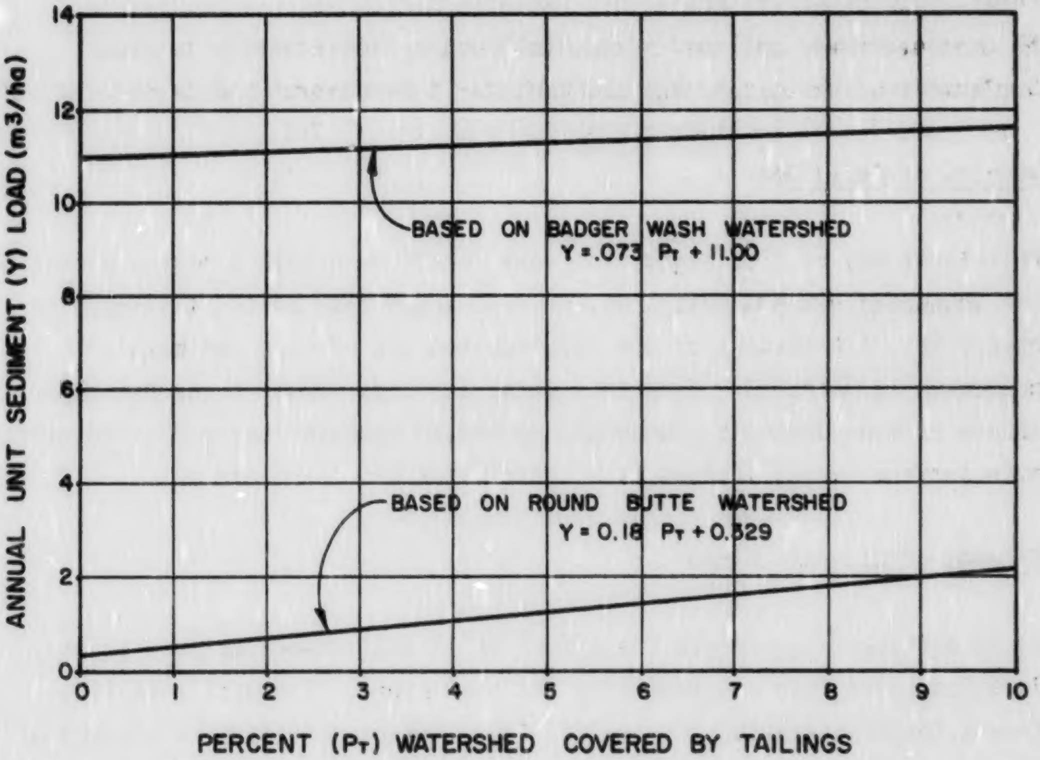


Figure 16. Effects on typical unit sediment load by tailings.

CAUSAL FACTORS AFFECTING POLLUTION

The following subsections summarize the factors that appear to be the predominant causes of mine drainage for the problem areas on which data was available.

Type of Pollutants

The length of streams affected in each state, by acid, metals, and sediment, is shown in Table 12. It can be seen that acid is the predominant cause of stream pollution. Acid is mentioned as a problem in 60 percent of the polluted areas, followed by heavy metals in about 50 percent of the cases, and sediment in 25 percent of the cases.

Sources of Pollution

Pollutants may be discharged from many locations within a mining operation. For instance acid and metals may be discharged from adits, tailings, or open pits. A breakdown of the reported sources of acid and metals is presented in Table 13. From this data, tailings appear to be the major source of mine drainage. Underground mining methods appear to predominate over surface mining methods as a contributor of mine drainage.

Effects of Minerals Mined

It is difficult to analyze the effect of minerals mined because at many locations more than one commodity has been mined. Frequently tailings from a former operation are remined for other commodities. A summary of the occurrances of minerals mined at problem areas is presented in Table 14.

TABLE 12. SUMMARY OF TYPES OF POLLUTION AND LENGTH OF STREAM AFFECTED

State	Acid		Metals		Sediment		Total	
	Number Cases	Stream Affected (km)	Number Cases	Stream Affected (km)	Number Cases	Stream Affected (km)	Number Cases	Stream Affected (km)
Arizona	1	[a]	1	[a]	1	[b]	3	[a]
Arkansas	1	[b]	-	-	2	[b]	3	[b]
California	22	87	16	62	5	38	26	89
Colorado	12	460	13	436	1	50	14	486
Idaho	2	105	7	133	4	[d]	15	133
Missouri	-	-	3	96	2	103	4	135
Montana	9	73	3	42	2	56	15	161
Nevada	1	[b]	-	-	-	-	2[e]	[b]
New Hampshire	-	-	1	5	-	-	1	5
New York	1	-	-	-	-	-	1	-
North Carolina	-	-	-	-	1	70[f]	1	70[f]
Oregon	5	37	-	-	1	16	5	37
Tennessee	1	35	2[g]	35	4[g]	60	4	60
Vermont	3	14	1	6	1	3	3	14
Washington	1	14	-	-	1	14	1	14
Wisconsin	1	10	1	10	-	-	1	10
Total	60	841	48	831	25	412	99	1220

[a] Lake affected 20 hectares.
[b] No estimate made.
[c] Only four mining districts contributing to 133 km of stream degradation. Length of polluted stream from other polluted areas unknown.
[d] No estimate available.
[e] One mine discharge causes aesthetic problem due to a colored discharge.
[f] Majority of problem from active operations.
[g] No data on length of stream.

TABLE 13. SUMMARY OF SOURCES OF ACID AND HEAVY METAL POLLUTION

	Number Of Cases [a]	Type Mining		Source of Pollution		
		Under-ground	Surface	Adits	Tailings[b]	Pits
Arizona	1	1	[c]	-	1	-
Arkansas	1	-	-	-	-	-
California	22[c]	15	5	9	10	2
Colorado	14	-	-	11	13	0
Idaho	7[e]	2	1	1	5	0
Missouri	3	3	0	2	2	0
Montana	11	8	5	7	9	5
Nevada	1	1	0	0	1	0
New Hampshire	1	[f]	-	0	1	-
New York	1	[f]	-	-	1	-
North Carolina	0	0	0	0	0	0
Oregon	5	2	-	2	1	-
Tennessee	2	2	-	-	2	-
Vermont	3	3	2	2	3	1
Virginia	2	1	1	-	2	-
Washington	1	1	-	-	1	-
Wisconsin	1	1	-	-	1	-
Total	76	40	14	34	53	8

[a] Number of cases in which acid and/or metals were reported.
[b] Includes waste, slag and overburden piles.
[c] Type of mining and source of pollution unknown.
[d] Type of mining only known at 18 locations. Source of pollution only known at 11 locations.
[e] Type of mining only known at two locations. Source of pollution only known at five locations.
[f] Type of mining unknown.

TABLE 14. SUMMARY OF MINERALS MINED AT PROBLEM AREAS

Mineral Mined	Times Reported at Problem Area
Gold	33
Copper	27
Silver	27
Lead	24
Zinc	21
Mercury	11
Iron	6
Barium, Sulfur, Uranium, Phosphate	3
Antimony, Mica	2
Aluminum, Cobalt, Cadmium, Bismuth, Manganese, Molybdenum, Arsenic, Quartz, Feldspar, Clay	1

The table shows that of the six metals most frequently reported, five occur as sulfides (see Table 2). Gold does not occur as a sulfide but is often found in its elemental form in sulfide deposits of other minerals. From this data it may be concluded that the form of the mineral (i.e., sulfide) is more significant than the mineral itself as an indicator of pollutant formation.

Climatological Effects

It was felt that there would be a relationship between the discharge of pollutants and the average annual runoff. To evaluate this theory it was decided to attempt a correlation between the average annual runoff and pollutant loading for each problem area. A plot of all problem areas is shown on Figure 17 along with average annual runoff.

A multiple linear regression analysis was run between the average annual runoff and pollutant loading. Unfortunately the data was too scattered to develop a significant curve fit. It was determined that with the data base for this study no correlation could be determined. However, by reviewing Figure 17 it can be seen that the major problem areas in California, Idaho, Montana, Colorado, and Missouri all occur in areas where the average annual runoff exceeds 2.5 centimetres per year. The discharge of pollutants is undoubtedly a function of climatic and other variables such as presence of pyrites, lithologic characteristics of the host ore body, volume of material displaced during mining, and amount of water flowing through mine workings and tailings.

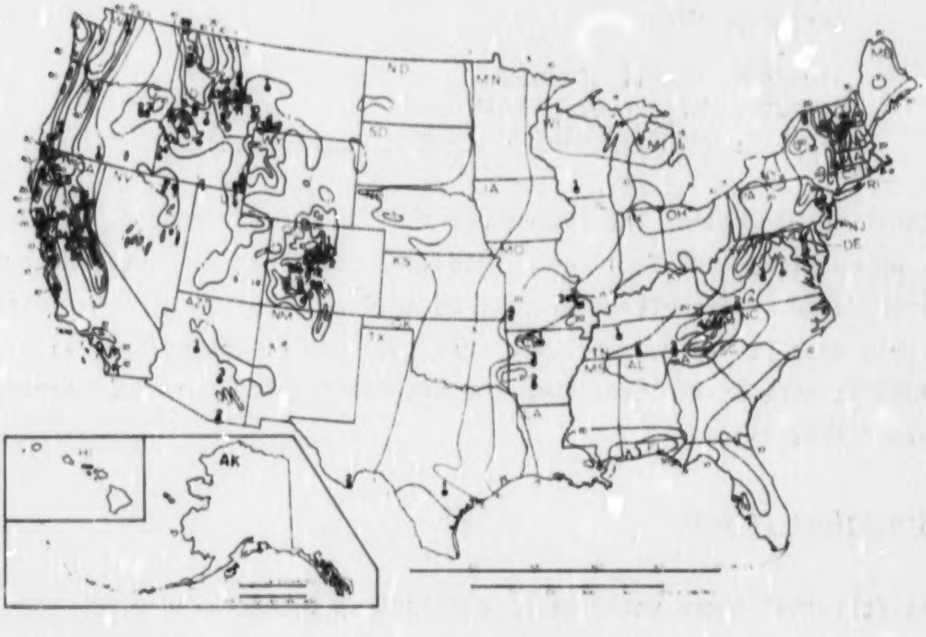


Figure 17. Average annual runoff in ore and mineral mining areas.

SECTION 7

ASSESSMENT OF CONTROL TECHNOLOGY FOR INACTIVE MINES

The objective of the second phase of this study was the evaluation of the state-of-the-art in prevention and control tecnology of water pollution from inactive mines. Pollution control technology for mineral mines is in its infancy and much has been extrapolated from the technology developed for coal mines. Many studies have been conducted and have proposed pollution abatement schemes. However, the majority of these have yet to be implemented and some are not based on proven technology. This section discusses only existing processes used to control pollution. Processes which are as yet untried, and which justify additional research, will be discussed in Section 8.

EXISTING TECHNOLOGY

The existing pollution control practices in the inactive mining industry are usually limited to control of infiltrating water and control of erosion from tailings. Mine drainage has been treated in only a few instances. There are no known cases where mine sealing has been used to prevent mine discharge.

INFILTRATION CONTROL

Water infiltrating into or flowing through tailings, is in many cases degraded by acid, metals, and increased turbidity. It has been shown that control of this water reduces discharges and the degree of contamination. A number of methods of controlling this flow exist such as surface blankets for tailings, surface water diversion and groundwater diversion.

Surface Blankets

Percolation of rainfall and snowmelt into tailings may be prevented by constructing an impermeable barrier on the surface of the tailings. This also reduces the availability of air to pyrites in the tailings. Impermeable blankets include chemical soil sealants, synthetic membranes, and clay blankets. Soils sealants and synthetic membranes are also useful in preventing erosion and are discussed in greater detail in a later subsection of this chapter.

At the Buena Vista Mine (CA-3) an attempt was made to place a clay blanket over the tailings. This had limited effectiveness since the tailings consisted of unconsolidated mercury retort slag. Settlement caused the blanket to crack in many places which reduced its effectiveness in controlling infiltration and reducing the available oxygen. Proper placement of an impervious blanket would have a much greater effect in reducing oxygen and water reaching the tailings.

Surface Water Diversion

Tailings have frequently been placed adjacent to or in water courses, diverting the stream and increasing the possibility of erosion and leaching of heavy metals. Surface runoff may also flow into tailings from adjacent higher ground.

The flow of water through tailings may be reduced by a number of methods:

- The stream may be relocated into a newly excavated watercourse;
- Streams may be rerouted through conveyance structures such as culverts or channels;
- Water flowing into tailings from adjacent higher ground may be diverted by construction of diversion ditches similar to those used to prevent erosion of highway cuts.

Groundwater Diversion

Rising groundwater has been known to come in contact with tailings increasing the concentration of metals in the water. Pumping of groundwater will lower the phreatic surface but the cost-effectiveness of pumping is questionable. A more feasible solution might be construction of free-draining collector drains to intercept the groundwater prior to its contact with the tailings.

Removal of Tailings in A Watercourse

Tailings have often been transported downstream along watercourses as a result of erosion of tailings piles or direct discharge of mill waste. When these deposited materials contain pyritic minerals or high concentrations of other metals, the stream may be contaminated by acid or dissolution of some of the metals. An effective method to reduce this pollution is removal of the tailings materials from the watercourse. The materials may then be placed in a site where the weathering process can be minimized such as an abandoned underground mine or landfill where weathering can be controlled.

At the Contrary Creek problem area in Virginia (VA-1) approximately 15 kilometres of stream has been polluted by mine drainage. A principal source of this pollution is from mine wastes, containing high concentrations of pyrites, which have been deposited in the watercourse.

A proposed solution, to a portion of the problem, is dredging approximately 4 kilometres of the stream to remove approximately 50,000 cubic metres of deposited mine waste. The dredged material would then be placed at a nearby site and revegetated and graded to minimize erosion and infiltration of rainfall.

Diversion of Polluted Discharges

Diversion and spreading of polluted drainage has met with limited success in controlling pollution at two mines in California, the Grey Eagle (CA-1) and Buena Vista CA-3). At CA-1 the adit discharge has been diverted and allowed to percolate into the ground preventing a point source discharge into the stream. The ultimate fate of these pollutants at CA-1 is unknown. They may be neutralized or exchanged by natural formations or they may form a non-point dispersed source of pollution to the stream or groundwater system. There has been little improvement in the stream water quality since drainage was diverted as naturally occurring acid from other sources still pollute the stream.

At CA-3 an acid discharge was applied on the ground through a sprinkler system and allowed to percolate. The metal parts of the system quickly disintegrated and the system was abandoned. This method of control may have limited application in the presence of calcareous formations and in locations where groundwater quality will not be affected. Recommendations for further research into this technology are discussed in Section 8.

RETENTION AND REGULATION OF MINE DRAINAGE

In areas of the country where the annual evapotranspiration (ET) exceeds average annual precipitation, the diversion of mine drainage to evaporation ponds may be an effective treatment scheme. The construction of an evaporation pond with an impermeable bottom liner would allow the water to evaporate from a polluted drainage. The dissolved constituents would precipitate out of solution and would be removed for ultimate disposal or recovery. The system may be effective where there is a suitable site for pond construction and where the mine drainage can be easily intercepted.

In the Shasta District area of California (CA-8) the most toxic stream in the area was Spring Creek which discharged high concentrations of metals into Keswick Reservoir on the Sacramento River. The Spring Creek Reservoir was built upstream of Keswick Reservoir and its construction has had a twofold effect on Keswick Reservoir. Sediment from the creek is now retained in Spring Creek Reservoir. The reservoir operation regulates discharges to insure that safe levels of copper concentrations in Keswick Reservoir are maintained. This method of pollution control reduces the toxic concentrations of pollutants through dilution but the mass flow of pollutants remains unchanged.

TREATMENT OF AMD

In Butte, Montana there is an active open pit mining operation and an inactive underground mining operation (Kelly Mine). The underground workings are continuously being dewatered. This water is presently mixed with lime and discharged into the tailings of the active operations where the metals reportedly precipitate as hydroxides. The properties of this untreated water are shown in Table 15.

TABLE 15. PROPERTIES OF KELLY UNDERGROUND MINE WATER

Constituent	Concentration (mg/1)
pH	1.8[a]
Iron	270
Zinc	145
Copper	68
Arsenic	0.9
Sulfate	4,600

[a] pH units.

A pilot scale demonstration project for removal of heavy metals by precipitation was performed on a mine waste in Colorado with encouraging results [EPA 1973m]. A two-stage process was used to treat the acid water. Lime was added in the first stage raising the pH which caused aluminum and iron to precipitate. Barium sulfide was added in the second step where the remainder of the heavy metals formed sulfide precipitates. The added barium was precipitated from solution as barium sulfate. The need for further research into this process is discussed in Section 8.

Backfilling Mine With Inert Material or Tailings

Mining methods such as cut and fill stoping require the backfilling of worked-out stopes prior to excavation of new ore. Common sources of backfill are mine waste, tailings and surface material. The backfill may either be placed hydraulically or pneumatically. Illustrations of cut and fill and methods of placing backfill are presented in Appendix B. Backfilling the worked-out stopes reduces the availability of oxygen to material in the stope and subsequent oxidation and pollution. If tailings or mine waste is used for backfill the size of external dumps and their associated pollution problems are reduced or eliminated. Another advantage to backfilling is that it reduces the possibility of subsidence.

Backfilling is not appliable to all mines since it is dependent on the mining method. The application of this technology, may in some cases, provide a solution to pollution from inactive mines. A disadvantage that must be considered is that subsequent recovery of other minerals in the tailings not extracted originally will be more costly if not impractical if tailings are used for backfill material.

EROSION PREVENTION

The principal methods for stabilization of milling wastes include:

- Physical - covering of the tailings with soil or other restraining materials.
- Chemical - application of chemicals which interact with fine-sized minerals forming a stable surface crust.
- Vegetative - initiation of plant growth on the tailings.

Physical Stabilization

Many materials have been used to physically stabilize fine tailings, preventing wind and water erosion and ultimately water pollution. The material used most often for stabilization is rock or soil borrowed from nearby areas. Soil often has the dual advantage of providing an effective cover and a suitable habitat for local vegetation.

Crushed or granulated smelter slag has been used in many instances to stabilize a variety of fine wastes, such as inactive tailings ponds. Unlike soils or country rock, slag cannot provide a favorable habitat for vegetation. Furthermore, suitable slag must be locally available.

Chemical Stabilization

Chemical stabilization involves application of chemical compounds which react with mineral wastes. This forms an impermeable crust or layer which reduces water and wind erosion of tailings. Chemicals are not as permanent as soil covering or vegetative stabilization. However, chemicals can be used on sites unsuited for the growth of vegetation because of harsh climatic conditions or the presence of toxic materials.

Studies have been conducted by Dean in which seventy chemical soil stabilizers were evaluated in the laboratory and field plots [Aplin 1973]. The comparative costs and effectiveness in reducing erosion were evaluated. The types of chemical compounds available for soil stabilization include: resinous adhesives and emulsions; lignosulfonate compounds; wax and resin compounds; and silicate compounds such as potassium and sodium silicates; bituminous by-products; and cationic neoprene emulsions.

Vegetative Stabilization

Revegetation of tailings is both a practical and aesthetically pleasing solution to bank stabilization. Vegetation is a good stabilizer for loose soil and it helps generate a pleasing appearance. The seeding of tailings has been the subject of much research. After hardy plant types are developed, they must be placed in proper conditions for continued growth. In many cases soil amendments such as fertilizer and organic matter such as wood chips or digested sewage sludge must be applied with the seed for proper germination. Methods of application have been studied by many investigators.

In Tucson, Arizona a vegetative stabilization program has been in operation for several years on active mine tailings. Many native and foreign plants have been studied with good results. The tailings have been seeded by hydromulching. As this is a desert area, the plant types that can be utilized are limited to desert flora [Aplin 1973].

In Toronto, Canada, an active mining operation is utilizing vegetative stabilization within the Canadian Shield area. This area is characterized by a moderate amount of rainfall, severe winters, and a short growing season. The program has been successful for both acid tailings (mining of various pyrites) and alkaline tailings (asbestos tailings). An interesting aspect is that the feasibility of commercial crop production has been demonstrated. The possibility of commercial crop production may stimulate further interest in revegetation of tailings in other areas [Aplin 1973].

SEDIMENTATION BASINS

The construction of sedimentation basins in watercourses below eroding tailings can reduce sediment loads downstream of the basin. The basins must be designed with sufficient hydraulic detention times to provide settling of the desired particles. The basins may also reduce dissolution of metals as the sediments would be restricted to a more compact area rather than distributed over a long stretch of stream. Two possible drawbacks of the system are periodic maintenance of the structure to remove sediment and the structure's prevention of fish migration.

DIFFICULTIES IN IMPLEMENTING CONTROL PROGRAMS

Proposals have been made for control of mine drainage at many of the problem areas. The majority of these proposals are based on existing technology previously cited. Implementation of the proposed programs is often cumbersome for many reasons.

The responsibility for pollution abatement is often clouded because the ownership of surface and mineral rights may be held by different parties. It is not uncommon that the present owners were not the operators during active mining but acquired the rights subsequent to mine shutdown. These owners are often reluctant to spend money on pollution control projects.

Mine operations are often shutdown when the grade of ore being mined is no longer economically feasible to process. Active mining may resume if economic conditions or technological advances again make mining profitable.

Owners are reluctant to seal workings, fill them with tailings, or in any way make reactivation more costly. As previously discussed, a tailings pile may be considered as a low grade ore body. Thus any reclamation efforts that complicate further reworking of these dumps may meet with stiff opposition from the owner.

Many of the problem areas are located in rugged mountainous terrain which have limited access especially in winter months. These access problems limit the choice of pollution abatement solutions to those which require little or no routine inspection or maintenance.

In order for a pollution abatement program to be implemented it must significantly reduce pollution and be cost effective. Much of the existing technology cited in this section has had limited success in pollution abatement and frequently the cost effectiveness is questionable. Additional research is needed to expand pollution abatement technology which is cost effective and which will reduce pollution.

In the past there has been little incentive for state regulatory agencies to perform assessments and propose control programs for mine pollution due to factors which include:

1) The mine owners reluctance to comply with pollution control requirements.

2) The lack of control technology and definition of "Best Management Practices".

3) On a statewide basis the mine pollution problem may appear less significant when compared to other types of pollution for which "Best Management Practices" are more easily defined.

4) Many of the available pollution control options include treatment schemes, the cost effectiveness of which is questionable.

Therefore, additional research is needed to expand pollution control and abatement technology which is cost effective and which will reduce pollution. This expanded research would allow a better definition of "Best Management Practices" for many problem areas and would create positive incentives for regulatory agencies to more fully assess problems in their areas.

SECTION 8

RECOMMENDED RESEARCH AND DEVELOPMENT

The final objective of this study was to prepare research and development programs to develop technology to control mine related water pollution. This section will discuss programs and recommend additional research to: 1) more adequately define pollution mechanisms; 2) develop pollution abatement technology which is technically and economically feasible. The recommended programs are discussed under the following categories:

- ° Evaluation of specific pollution problems not sufficiently documented;
- ° Development of evaluation techniques necessary to adequately monitor pollution;
- ° Research into the chemistry related to mine drainage;
- ° Research and development in prevention technology;
- ° Research and development in treatment technology;
- ° Research and development in mining technology to reduce or eliminate polluted discharges upon mine shutdown;

SPECIFIC PROBLEMS NOT SUFFICIENTLY DOCUMENTED

It has become apparent that past mining activities may be the source of surface and groundwater pollution problems which were not sufficiently documented to be included in this study. Groundwater pollution from inactive mines and mercury discharged during active gold mining are two examples of poorly documented pollution problems which should be studied in depth.

EFFECTS OF MINE DRAINAGE ON GROUNDWATER QUALITY

The data search conducted in this study revealed many cases of polluted surface waters, but little information was available concerning the occurrence or magnitude of groundwater pollution. For example, the mining related pollution of the groundwaters in the Cataldo Mission Flats area of Idaho has been the subject of extensive investigation. Acidic waters, high in metal concentrations, were shown to have moved more than 700 metres in this shallow aquifer. In the Globe-Miami District in Arizona, groundwater quality has degraded over the years as a result of active and inactive mining operations. In Tucson, Arizona large copper mill tailings (currently active) are being investigated as a possible source of groundwater quality degradation.

Groundwaters are a substantial component of the nation's water resources and since groundwater pollution is difficult to eliminate, it is recommended that several sites be chosen to investigate the potential of groundwater pollution from mining activities. Specific areas of interest should include:

- Investigation of the mobility of pollutants, such as acids and metals, through tailings and aquifer systems;
- Determination of the effects of tailings construction methods and particle size of tailings on the permeability of the tailings and the mobility of pollutants;
- Determination of a suitable tracer which may act as an indicator of mine related water pollution.

ASSESSMENT OF MERCURY IN SURFACE WATERS FROM GOLD MILLING

In the 19th and early 20th centuries the gold milling process consisted of passing the crushed ore over mercury amalgamation plates to recover the gold particles. Most of the mercury produced prior to 1900 was used in gold milling and much of it was discharged inadvertently into surface waters as free mercury. The discharge of free mercury into surface waters may result in the formation of methylmercury compounds and subsequent bioaccumulation by fish species.

Although the mercury amalgamation process has been for the most part replaced by cyanide leaching, its use has continued at some locations. For example, the Homestake Mine in South Dakota practiced amalgamation until 1970. At this location, high concentrations of mercury have been measured in the stream sediments and surface waters below the mill [EPA 1971m]. Along the Jordan River an old gold and silver mining area in Idaho, high concentrations of mercury have been measured in the flesh of fish.

A research program should be conducted to identify the location of mills that produced a significant amount of gold. Particular emphasis should be placed on states such as Alaska, Arizona, California, Colorado, Idaho, Montana, Nevada, South Dakota, and Utah which historically have produced significant quantities of gold. Once the locations of the mills have been established, large mills should be selected for detailed site testing, since the amount of mercury discharged is probably proportional to the gold produced. Testing should include sampling stream sediments and fish for high mercury content. Benthic diversity tests should be performed above and below the affected area to determine the length of stream affected.

IMPROVEMENT OF POLLUTION MONITORING TECHNIQUES

The assessment phase of this study was greatly complicated by lack of consistency in water quality sampling and data gathering criteria used by the agencies involved. Water quality analysis ranged from measurements of pH and a few metallic constituents to a complete water quality analysis consisting of both total and dissolved fractions of heavy metals and the significant anions. All too often data regarding the type of mining, mineral mined, or host ore bodies was unavailable or incomplete.

MONITORING MANUAL

The lack of consistency in data collection criteria and analysis has emphasized the need for an assessment manual which would standardize testing and evaluation criteria. Complete testing of all possible metals at each site is expensive and might easily be avoided. The following objectives should be accomplished in the preparation of the manual:

- Develop selective testing criteria. As shown in Figure 2 various host ore bodies may be expected to contain certain trace elements. A matrix could be developed whereby the suspected pollutants would be selected for testing based upon the mineralogic characteristics of the ores in a watershed.
- Review and establish standardized sampling procedures. The constituents of mine drainage are continuously reacting in the aquatic environment. Thus, it is necessary to collect and preserve the samples properly if meaningful test results are to be obtained. Some constituents, such as pH, must be measured in-situ as laboratory results will not accurately duplicate field conditions. Often when metals concentrations are reported, it is unknown if the tests were run for the total metals or only the dissolved fraction. The proposed procedures should establish whether analysis should include total or dissolved metals or both, as the collection and preservation techniques vary for each test.
- Develop a predictive model to determine loading functions of pollutants from active and inactive mining areas. Models have been proposed in coal mining areas but their applicability to metal mining areas is unproven. These models should be developed to assist in the prediction of the effectiveness of water pollution abatement programs.
- Determine if a suitable tracer of AMD exists in metal mining areas and standardize its use in the identification of mine related pollution. As discussed previously, sulfate has been used as an indicator of AMD in coal mining areas but the system has a disadvantage due to the often naturally high sulfate concentrations in the waters of metal mining areas.

CHEMISTRY RELATED TO MINE DRAINAGE

As discussed in previous sections, the chemistry of mine drainage is complex and not fully understood. Acid mine waters and natural weathering are responsible for the dissolution of minerals. Once these minerals enter receiving waters, they may undergo a series of complex interrelated reactions. The mineral equilibrium is a function of Eh, pH, temperature, and constituents of its surrounding solution and atmosphere. Research is recommended in the following areas in order to expand the knowledge of the chemistry and significance of some of the pollutants:

- Determine the mechanisms of transportation and removal of heavy metals in surface waters.
- Determine the significance of the formation of organometallic complexes on the transportation and removal systems. Some investigators believe that formation of these complexes may allow the metals to remain in solution longer than the analysis of the solubility products would predict.
- Determine the effects of organometallic complex on the toxicity of dissolved metals to aquatic species.
- Expand knowledge concerning the ultimate fate of metals in the aquatic environment affected by mine drainage. As discussed in Section 5, the metals discharged into surface waters ultimately settle into the benthos of streams and lakes but it is suspected that the metals may later be chemically or biologically redissolved, becoming a low-level source of non-point source pollution for many years.

PREVENTION TECHNOLOGY

The currently utilized prevention and control technology for inactive mines was discussed in Section 7. Other existing technology, such as that used for pollution abatement in coal mining, is available. However, its effectiveness in pollution control at inactive metal mines has not been demonstrated. There are also unproven proposed abatement schemes which may prove viable. This section discusses pollution prevention schemes where additional research is recommended.

AIR CONTROL

The rate-limiting reaction in acid formation is the oxidation of ferrous iron by molecular oxygen. Experiments have shown that the rate of acid production from pyrite oxidation is proportional to the partial pressure of oxygen. In coal mining areas, mine sealing has been attempted, for years, to reduce acid formation by limiting the quantity of oxygen in the mine. There are three methods used to seal mines: 1) sealing all openings exposed to the atmosphere; 2) displacing the air with an inert gas; 3) displacing air in the mine with water.

Air Seals

Air seals have been tried on coal mines but have had a limited effect in reducing the discharge of pollutants. Investigations have shown that oxygen levels must be reduced to 1 percent to achieve a 90 percent reduction in the formation of acid. The difficulty with air seals is that changes in barometric pressure cause the mine to "breathe", making it difficult to reduce the oxygen content below an average of 15 percent [Hill 1975a].

Breathing is caused in part by the fact that these free-draining coal mines are excavated in coal deposits which are relatively close to the surface and which have a fractured and permeable overburden. This allows air to pass in and out of the mine in responce to changes in marometric pressure. Many metal or "hard rock" mines are excavated in competent rock with more cover than coal mines. Thus, it is expected that the breathing problem may be reduced. It is therefore recommended that a demonstration project be undertaken to determine the feasibility of installing of air seals to reduce pyrite oxidation and subsequent heavy metal liberation.

Inert Atmosphere

Another method of eliminating oxygen in a mine is displacing oxygen with an inert gas. Laboratory tests have shown that nitrogen and methane are the most effective inert atmospheres for the prevention of pyrite oxidation. A possible source of an inert atmosphere is the biological decomposition of organic matter in an anaerobic environment. The gas produced consists principally of methane and carbon dioxide.

Studies in sanitary landfills have shown that initially carbon dioxide is the major constituent of the gas since the process is partially aerobic. When oxygen has been consumed methane and carbon dioxide are produced in approximately equal quantities. It has also been shown that the rate of decomposition and gas production may be regulated by controlling the moisture content of the organics.

It is suggested that organic wastes may be placed in a mine and by properly controlling the moisture content of the organics the rate of gas generation could be regulated to overcome problems associated with breathing. Thus, the inert atmosphere supplied would greatly reduce pyrite oxidation. Control of gas production would also optimize the life of the system. In the initial phases of the project it may be necessary to route the mine drainage around the organics as the acid and metals may be toxic to the biological process. If this were the case it would be necessary to provide a fresh water source to control the moisture.

It is recommended that a research program be conducted to investigate this theory. Specific components of the program would include:

- Selection of a suitable mine site where the problems of breathing could be minimized and which is in close proximity to a suitable source of organics;
- Determine the toxicity of mine drainage to the biological process and, if toxic, provide a bypass system to avoid direct contact between mine drainage and the organics;

- Determine the rate of gas production and regulate the moisture content to overcome breathing;

- Determine the effectiveness of the inert atmosphere in reducing the formation and discharge of mine drainage.

Mine Flooding

When pyrite is submerged underwater the production of acid essentially ceases. It has been demonstrated in coal mines that bulkheads may be constructed which cause the mine to flood and thus limit air and reduce the acid production. A possible drawback is that mine drainage may leak around the bulkhead through fractures in the rock strata. The bulkheads must also be periodically inspected for structural integrity to insure against a sudden failure. Bulkhead seals have demonstrated that acid formation can be reduced by more than 95 percent, but little is known of the ability to reduce the dissolution of minerals. It is possible that proper construction of a well designed bulkhead in competent rock may eliminate the discharge completely. It is recommended that a demonstration project be undertaken to determine the effectiveness of bulkhead seals on inactive metal mines.

EROSION PREVENTION

As discussed in Section 7, the three methods of erosion prevention of tailings are physical, chemical, and vegetation stabilization. Erosion prevention is an important technology used in other sectors of the economy and is regularly used on projects such as highway and new construction embankments.

The technical problems associated with vegetative stabilization such as lack of adequate nutrients and organic matter for proper growth and the presence of toxic compounds makes vegetative stabilization of tailings a unique problem. Tailings must be properly prepared prior to revegetation if the plants are to survive and propagate. The surface preparation includes: addition of necessary nutrients, normal microbial population must be seeded, excessive salts and phytotoxicants (such as metals) must be removed, and the soil must be consolidated to prevent blowing sand which destroys young plants. Costs for this can be high, as shown in studies by Ludeke the initial application of nutrients by hydroseeding can be expected to cost approximately $3,200 per hectare [Alplin 1973]. The cost of this type of application in remote areas would be escalated greatly due to limited access.

It is recommended that research be conducted to develop plant species with a high resistance to the toxic environment to avoid the high cost of tailings preparation prior to revegetation. Additional topics for further research might include investigation of plants species which extract heavy metals from the soil and concentrate the metals in the plant tissue. Hybridization of these plants may produce plants which could be economically harvested to recover the concentrated metals.

TREATMENT

A desirable solution to eliminate water pollution at inactive mines is the prevention of its formation. Often this may be impractical technologically and not cost effective. Treatment of mine drainage based on proven technology is a positive approach to the elimination of a polluted discharge. However, treatment processes have some inherent disadvantages which include: continuous operation and maintenance, purchase of chemicals, sludge disposal, high initial cost, and site availability. Many treatment processes developed to treat discharges from coal mining may be applicable in metal mining areas, but their effectiveness in removal of high concentrations of metals is unknown. Treatment includes both physical-chemical and biological processing.

NATURAL MINERAL FORMATIONS AS TRAPS FOR DISSOLVED IONS

Naturally occurring silicate minerals exhibit a unique property of ion adsorption or ion exchange. Such silicate minerals (and the natural geological formation containing these minerals) might be used for selective adsorption or ion exchange of dissolved heavy metals and acid in mine drainage. Similarly, many types of clay can also act as an ion exchange medium.

In silicon minerals as the oxygen-silicon ratio increases from quartz to the olivines, a greater percentage of the oxygen bonding power is available for bonding to cations other than silicon. Hence, with an increasing oxygen-silicon ratio, there is increasing oxygen-to-metal bonding capability. Upon the fracturing of a silicate mineral crystal, the oxygen-metal bond, which is almost entirely ionic in character, should break more easily than the stronger oxygen-silicon bond, resulting in a greater number of unsatisfied negative charges on the surface. If the mineral is then immersed in a liquid containing hydrogen ions, these negative charges will neutralize free hydrogen ions in the solution. An increase in the degree of adsorption of hydrogen ions is to be expected as the oxygen-silicon ratio in the crystal structure increases [Deju 1965].

It is recommended that a research and development program be undertaken with the following objectives:

- ° Identify natural silicate formations which exhibit acid neutralizing capabilities;
- ° Determine the feasibility of treatment of AMD with these formations;
- ° Identify pollution problem areas in close proximity to silicate formations with acid neutralizing properties;
- ° Conduct demonstration projects to determine the effectiveness of silicates as an acid neutralizer;
- ° Determine the cost effectiveness and life expectancy of this treatment process.

Other natural mineral and rock formations may have acid neutralizing properties similar to silicates. Other research programs should be conducted to determine if other such formations exist and their effectiveness as an acid neutralizer.

BOTANICAL TREATMENT

Some plant species are known to have the ability to extract heavy metals from the soil and to concentrate the metals in the plant tissue. The feasibility of utilizing these plants in a treatment process for mine drainage should be investigated further. The water hyacinth and some natural bogs have this ability.

Recent studies have shown that the water hyacinth has the ability to remove metals from solutions and to concentrate the metals as much as 10,000 times [Water Newsletter 1976]. The plants have proven to be an effective removal system for lead, mercury, and other pollutants. The plants also have shown that a single plant can to produce up to 60,000 plants in eight months with proper harvesting and disposal. The combination of the plants ability to concentrate metals and proliferate in large quantaties may prove to be an effective treatment process for the removal of the dissolved constituents in mine drainage.

A research program should be conducted to:

- Determine if hyacinths can proliferate in an acidic environment;
- Determine threshold toxicity of various metals to the plants;
- Determine its effectiveness in the removal of pollutants.

Bog iron deposits were formed by waters, containing high concentrations of ferrous iron, flowing through natural bogs. These bogs removed the iron from solutions and concentrated it in the cellular structure of the plants. Feasibility studies should be conducted to determine if natural bogs can effectively remove pollutants from mine drainage. Further research is recommended to determine if other plants have the ability to remove pollutants.

PHYSICAL CHEMICAL TREATMENT

Most of the existing treatment processes for mine drainage (from both coal and ore mining areas) are physical-chemical methods. Many of the processes developed for coal mine drainage may be applicable to metal mine drainage. However, the effectiveness of these processes in the removal of high concentrations of heavy metals is unknown and should be verified. The most common treatment process in coal mining areas is the addition of lime which neutralizes the acid and causes the dissolved ferric iron to precipitate. This process and other possible processes are discussed further.

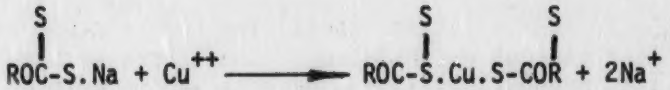
Precipitation

As discussed in Section 7 pilot scale studies have shown that metals may be removed from mine drainage by a two-step process. Lime is added in the first step to raise the pH causing iron and aluminum to precipitate. Barium sulfide was added in the second step where the remainder of the heavy metals formed insoluble sulfide precipitates. The added barium was precipitated from solution as barium sulfate. A drawback of this system is the high cost of barium sulfide.

It is recommended that further research be conducted to develop an inexpensive sulfide source for this process. The biological reduction of sulfate, which is abundant in mine drainage, may be a possible sulfide source. This is known to occur in sanitary landfill where sulfides are produced when brackish water, high in sulfates, infiltrates into the solid waste. If an economical sulfide source is discovered it is recommended that a demonstration project be undertaken to determine its cost effectiveness and effectiveness in removing pollutants.

Foam Flotation

As discussed in Section 4, flotation is presently used for beneficiation in the mineral industry. However, as foam flotation, it may prove to be a feasible process in the removal of heavy metals in mine drainage and ore concentration wastes at active operations. The process consists of addition of an organic collector forming an anionic complex which may be removed from solution by flotation. These collectors may be an amine or a simple cation. An example of this type of reaction is:



$$\mathrm{RO}\overset{\overset{\textstyle \mathrm{S}}{|}}{\mathrm{C}}\mathrm{\text{-}S.Na} + \mathrm{Cu}^{++} \longrightarrow \mathrm{ROC\text{-}}\overset{\overset{\textstyle \mathrm{S}}{|}}{\mathrm{S}}\mathrm{.Cu.S\text{-}CO}\overset{\overset{\textstyle \mathrm{S}}{|}}{\mathrm{R}} + 2\mathrm{Na}^+ \qquad (13)$$

(xanthate) (copper xanthate)

The development of the existing flotation technology is directed toward economic recovery of minerals and is not directed toward recovery of metals in the concentrations encountered in mine drainage. It is recommended that additional research be conducted in this field to determine if metals can be removed from solution in the concentration encountered in mine drainage.

Reverse Osmosis

Treatment of an acid discharge from a coal mine by reverse osmosis (RO) has been shown to be an effective method of treatment which produces a high quality effluent [EPA 1973b]. Recovery was limited by calcium sulfate scaling which might be avoided by the addition of a sequestering agent. The high rejection rates obtained by RO for calcium, iron, and maganese indicates that RO may be a technically feasible process for treating AMD, from ore and mineral mining. However, application of the process would be greatly limited by its high initial cost and continual operation and maintenance. Since RO is a concentration process the disposal of waste brine imposes limitations on its application for mine drainage pollution abatement.

It is unknown if the process will exhibit high rejection rates for the other disolved metals in AMD. Therefore it is recommended that a feasibility study be performed to determine the applicability of RO to treatment of AMD with high concentrations of heavy metals. If RO proves successful, demonstration projects should be undertaken.

EFFECTS OF MINING TECHNIQUES ON POLLUTION CONTROL

One of the most significant factors affecting the potential for pollution from a mine is the method of mining. A mine working may be either free draining or may need pumping to discharge intercepted groundwater. The flow of groundwater has in some instance been the limiting factor in the excavation of a mine. Some tunnels such as the Sutro near Virginia City, Nevada and the Argo near Clear Creek, Colorado were constructed primarily as drainage tunnels. Drainage from the Argo is one of the primary sources of pollution in Clear Creek.

When the mine is deactivated, flow can be expected to continue from free-draining mines and if pyrites are present, acid discharge will result. Mines that must be pumped will fill with water and may produce no discharge. At present, there are no specific guidelines available delineating the various methods which can be used to properly deactivate a mine and prevent the formation and discharge of polluted drainage.

It is recommended that a manual be prepared summarizing applicable prevention, reclamation, and monitoring procedures. The manual should include topics such as:

- Removal of broken ore or mineralized waste from the workings;
- Sealing tunnels, workings, shafts, etc., diversion of surface water from mine openings and tailings;
- Surface reclamation;
- Tailings sealing and revegetation;
- Construction of evaporation ponds;
- Backfilling mine with inert material or tailings;
- Flooding the workings;
- Establishing proper monitoring techniques.

SECTION 9

BIBLIOGRAPHY

American Water Resources Association. Water Resources Problems Related to Mining. Edited by Hadley, R. F. and Snow, D. T. 1974.

Aplin, C. L. and Argall, G. O. Ed. Tailing Disposal Today. Miller Freeman Publications, Inc., San Francisco, California. 1973.

Appalachian Regional Commission. Determination of Estimated Mean Mine Water Quantity and Quality from Imperfect Data and Historical Records. January, 1973.

Arizona Daily Star. Tucson, Arizona. "Uranium Remnants Radiating Part of Town." March 7, 1976.

Avotins, P. and Jenne, E. A. "Time Stability of Dissolved Mercury in Water Samples. No. 2. Chemical Stabilization." Journal of Environmental Quality. Volume 4, No. 4. 1975.

Baker, D. H., Bhappu, R. B. "Specific and Environmental Problems Associated with the Processing of Minerals, Extraction of Minerals and Energy."

Boyles, J.M., et al. Impact of the Argo Tunnel Acid Mine Drainage and Mine Tailings on Clear Creek and Possible Abatement Procedures. Colorado School of Mines. December 1973.

Brezina, E. R., et. al. "Effects of Acid Mine Drainage on Water Quality of a Reservoir." Journal of Water Pollution Control Federation. Volume 42, No. 8, Page 14, 29. August, 1970.

California Division of Mines and Geology. Principal Areas of Mine Pollution. June 1972.

________. 67th Report of the State Geologist. 1973-74.

California Regional Water Quality Control Board. Central Valley Division. Pre-feasibility Study Corona Mine Waste Demonstration Abatement Project. November, 1971.

________. Lahontan Region. Report on Pollution of Leviathan Creek Brian Creek, and the East Fork of the Carson River Caused by Leviathan Sulfur Mine. January, 1975.

California State Water Resources Control Board. Water Quality Criteria. McKee and Wolf. 1963.

Code of Federal Regulations, Title 10, Chapter 1, Part 20. Standards for Protection Against Radiation.

Colorado Department of Health, Water Pollution Control Commission. Guidelines for Control of Water Pollution from Mine Drainage Adopted November, 1970.

Colorado Water Conservation Board. Circular No. 21. Effects of Mine Drainage on the Quality of Streams in Colorado 1971-1972. Wentz, D. A. 1974.

_______. Circular No. 25. Effects of Metal-Mine Drainage on Water Quality in Selected Areas of Colorado 1972-73. Moran, R.E. and Wentz, D.A. 1974.

The Daily Sentinel. Grand Junction, Colorado. Newspaper articles over the period 1970-1975 on use of radioactive climax tailings for construction fill and concrete in Grand Junction area. Also studies on radiation effects and removal of tailings.

Deju, R. A., and Bhappu, R. B. Surface Properties of Silicate Minerals. State Bureau of Mines and Mineral Resources. New Mexico Institute of Mining and Technology, Socorro, New Mexico. 1965.

Duncan, David L. and Eadie, Gregory G. Environmental Surveys of the Uranium Mill Tailings Pile and Surrounding Areas, Salt Lake City, Utah. Environmental Protection Agency, National Environmental Research Center, Las Vegas, Nevada. August, 1974.

Emrich, G. H. and Merritt, G. L. "The Effects of Mine Drainage on Groundwater." Groundwater. Volume 7, No. 3. June, 1969.

Energy Research and Development Administration (ERDA). Statistical Data of the Uranium Industry. January, 1975.

Federal Water Pollution Control Administration, Northwest Region, Alaska Water Laboratory. Effects of Placer Mining on Water Quality in Alaska. February, 1969.

Fifth Symposium on Coal Mine Drainage Research. Mellon Institute. Coal in the Environment Technical Conference. October, 1974. Louisville, Kentucky.

Flaxman, E. M. "Predicting Sediment Yield in Western United States." Journal of Hydraulics Division. American Society of Civil Engineers. December, 1972.

Follett, R. H. and Willson, J. C. Pollution of Lynx Lake by Drainage from the Abandoned Sheldon Mine. Arizona State Department of Health. August, 1969.

Fourth Symposium on Coal Mine Drainage Research. Mellon Institute. April, 1972. Pittsburg, Pennsylvania.

Galbraith, J. H., et. al. "Migration and Leaching of Metals from Old Mine Tailings Deposits". Groundwater. Volume 10, No. 3. May-June, 1972.

Garrels, R. M., and Christ, C. L. Solutions and Mineral Equilibrium. Freeman and Cooper. 1965.

Hem, J. D. and Durum, W. H. "Solubility and Occurrence of Lead in Surface Water." Journal of American Water Works Association. August, 1973. Page 562.

Hill, R. D. "Acid Mine Water Control". Mining Environmental Conference. Rola, Missouri. April 16, 1969.

________. "Neutrolosis Treatment of Acid Mine Drainage." 26th Annual Purdue Industrial Waste Conference, Layfayette, Indiana. May, 1971.

________. "Restoration of a Terresterial Environment-The Surface Mine." ABS Bulletin. Volume 18, No. 3. July, 1971.

________. "Treatment of Ponds and Pits Filled With Acid Mine Drainage." March, 1974.

________. "Non-point Pollution from Mining and Mineral Extraction." Presented at Conference on Non-point Sources of Water Pollution, Virginia Water Resources Research Center, Blacksburg, Virginia. May, 1975.

________. "Sediment Control in Surface Mining." Polish-U.S. Symposium. Environmental Protection in Open Pit Coal Mining, Denver, Colorado. May 1975.

Hines, W. G. Preliminary Investigation of Mercury-Hazard Potential Warm Springs Dam and Lake Sonoma Project, Dry Creek Basin, Sonoma County, California. USGS Water Resources Division, Open file report. Menlo Park, California. November, 1971.

Jenne, E. A. "Controls on Mn, Fe, Co, Ni, Cu, and Zn Concentrations in Soils and Water: the Significant Role of Hydrous Mn and Fe Oxides". Reprint from Advances in Chemistry Series Number 73, Trace Organics in Water. 1968.

Jenne, E. A., and Avotins P. "The Time Stability of Dissolved Mercury in Water Samples. No. 1. Literature Review." *Journal of Environmental Quality*. Volume 4, No. 4. 1975.

Jennett, J. C., Wixson, B. G. "Problems in Lead Mining Waste Control." *Journal Water Pollution Control Federation*. Volume 44, No. 11. November, 1972.

King, D. L, et. al. "Acid Strip Mine Lake Recovery". *Journal of Water Pollution Control Federation*. Volume 46, No. 10. October, 1974: 2301.

Lee, Dich. *Metallic Contaminants and Human Health*. Academic Press. 1972.

Loy, L. D. "Deep Mine Pollution-Solving the Hole Problem." Spring meeting of the Interstate Mining Compact Commission. Date unknown.

Lynn, R. D. and Arlin, Z. E. "Anaconda Successfully Disposes Uranium Mill Wastewater by Deep Well Injection." *Mining Engineering*. July, 1967: 49-52.

Missouri Department of Conservation, Aquatic Series No. 10. *Water Quality Survey of the Southeast Ozark Mining Area, 1965-1971*. Ryck, F. M. August, 1974.

Montana Department of Health and Environmental Sciences. *Appraisal of Water Quality in the Boulder River Drainage and Potential Methods of Pollution Abatement or Control*. R. D. Braico, and M. K. Botz. December, 1974.

Montana, Department of Natural Resources and Conservation. Progress Report No. 13. *Annual Report on Studies Concerning Acid Mine Drainage, Stream Pollution Abatement Near Hughsville, Montana*.

________. *Annual Report Acid Mine Drainage Control-Feasibility Study, Cook City, Montana*. Wallace, J. J., et al. April, 1975.

National Academy of Sciences. *Underground Disposal of Coal Mine Waste*. 1975.

Nevada Bureau of Mines. Bulletin No. 66. *Interpretation of Leach Outcrops*. Blanchard, R. Mackey School of Mines, University of Nevada. 1968.

Oregon Department of Planning and Development. "A Method of Electrowinning Copper and Zinc (or Brass)." Menidest, R. E. December, 1962.

Patterson, R. M. "Stowing in Abandoned Mines for Drainage Control". Interstate Mining Compact Meeting. May 16, 1974.

Pennsylvania State University, Department of Civil Engineering. Institute for Research on Land and Water Resources. Crushed Limestone Barriers: A Basic Feasibility Study in the Neutralization of Acid Streams. R. E. Jarrett and R. Koumpz. Water Resources Research Publication 2-66. June, 1966.

Pine, R. E. The Effects of the Holden Mine Tailings on the Aquatic Insect Fauna of Railroad Creek. State of Washington Water Pollution Control Commission. October, 1967.

Pugsley, E. B. Removal of Heavy Metals from Mine Drainage in Colorado by Precipitation. Master Thesis, University of Denver. March, 1970.

Reimers, et. al. "Sorbtion Phenomenon in Organics of Bottom Sediments." Reprinted from Progress and Water Technology, Volume 7. K. Krenke., Editor. 1975. Oxford. Permagon Press.

Roase, J. V., Dudley, J. G. Radiochemical and Toxic Pollution of Water Resources, Grants Mineral Belt, New Mexico. AIME Annual Meeting, Las Vegas, Nevada. February, 1976.

Santa Clara County Parks and Recreation. Draft Environmental Impact Report for the Proposed Almaden Quicksilver Park Equestrian Center. Earth Metrics Incorporated. May 16, 1975.

Sawyer and McCarty. Chemistry for Sanitary Engineers. McGraw-Hill. 1967.

Scott, R. B., Wilmoth, R. C., and Hill, R. D. "Cost of Reclamation in Mine Drainage Abatement, Elkins Demonstration Project." Society of Mining Engineers AIME Transactions. Volume 252. June, 1972.

Second Research and Applied Technology Symposium on Mine-land Reclamation. Coal and Environment Technical Conference. October 1974. Louisville, Kentucky.

Sizemore, D. R. "The Effects of Acid Mine Drainage on Chestnut Creek in Virginia." Masters Thesis, Virginia Polytechnic Institute. August, 1973.

Stumm, W., Lee G. F. "Oxygenation of Ferrous Iron." Industrial Engineering Chemistry. Volume 53: 143-146. 1961.

________. Aquatic Chemistry. Wiley-Interscience, 1970.

Task Committee on Preparation of Sedimentation Manual. "Sediment Sources and Sediment Yield." Journal of Hydraulics Division. American Society of Civil Engineers. June, 1970: 1283.

Third Symposium on Coal Mine Drainage Research. Mellon Institute. May, 1970. Pittsburg, Pennsylvania.

Third Symposium on Surface Mining and Reclamation, Volumes 1 and 2. Coal Conference on Expo II, October, 1975. Louisville, Kentucky.

Trakowsky, A. C. "Abandoned Underground Mines." Interstate Mining Compact Commission, Spring Meeting, Pipesden, West Virginia. May, 1974.

U.S. Atomic Energy Commission. Summary Report, Phase I Study of Inactive Uranium Mill Sites and Tailings Piles, plus back-up data on various millsites. October, 1974.

________. Grand Junction Office. Uranium Industry Seminar. October, 1974: 13-38.

U.S. Bureau of Mines. Penn Mines Slag Dump and Mine Water Calaveras County, California. Wiebelt, F. J. and Ricker, F. March, 1948.

________. Hydraulic Model Studies for Backfilling Mine Cavities. REC/ERC/75/3. Carlson, E. J. March, 1975.

________. Environmental Effects of Underground Mining and of Mineral Processing. Draft Report.

________. Surface Mining in our Environment.

________. Report of Investigation No. 8036. Paulmetric Materials for Sealing Raidon Gas into the Walls of Uranium Mines. J. C. Franklin, et al. 1975.

U.S. Department of Health, Education, and Welfare, Federal Water Pollution Control Administration. Disposition and Control of Uranium Mill Tailings Piles in the Colorado River Basin. March, 1966.

________. Technical Report W62-17. Process and Waste Characteristics at Selected Uranium Mills. 1972.

U.S. Department of the Interior, Office of Water Research and Technology. PB/239 523. Acid Mine Water, a Bibliography. February, 1975.

U.S. Forestry Service. "Chequamegon and Nicolet, National Forest, Wisconsin, Hunt, Clint." Iron-Brule River Report. March 1974.

U.S. Geological Survey, Water Supply Paper No. 1473. Study and Interpretation of Chemical Characteristics of Natural Waters. J. D. Hem. Reprinted 1965.

________. 622. The Absorption of Silver by Poorly Crystalized Manganese Oxides. D. J. Anderson, et. al.

________. Open File Report. Mercury in the Water of the United States. 1970-71. Jenny, E. A. April, 1972.

______. Colorado Water Resources Circular No. 25. Effects of Metal-Mine Drainage on Water Quality in Selected Areas, 1972-73. Moran, R. E. and Wentz, D. A. 1974.

______. Open File Report. Limnological Data From Selected Lakes in the San Francisco Bay Region, California. Britton, L. J., et. al. 1974.

U.S. Public Health Service. Report on Investigation of Groundwater Pollution; Grants-Bluewater, New Mexico. Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio. August, 1957.

U.S. Environmental Protection Agency. 14010 DKN 11/70. Microbial Factor in Acid Mine Drainage Formation. July, 1970. Water Pollution Control Research Series.

______. 14010 ETV 08/70. Neutralization of High Ferric Iron Acid Mine Drainage. Wilmoth, R. C. and Hill, R. D. August, 1970. Water Pollution Control Research Series.

______. 14010 FMH 12/70. Treatment of Acid Mine Drainage by Ozone Oxidation. December, 1970. Water Pollution Control Research Series.

______. 14010 FKK 12/70. Underground Coal Mining Methods to Abate Water Pollution. December, 1970. Water Pollution Control Research Series.

______. A Reexamination of the Coeur D'Alene River. Jack E. Sceva and William Schmidt. September, 1971.

______. Grant No. 14010FPR. Acid Mine Drainage Formation and Abatement. Ohio State University Research Foundation. Water Pollution Control Research Series. April 1971.

______. Grant No. 18050EEC1271. Acid Mine Pollution Effects on Lake Biology. Smith, R. W. and Frey, D. G. Water Pollution Control Research Series. December 1971.

______. 14010 DYG 08/71. Acid Mine Waste Treatment Using Reverse Osmosis. August, 1971. Water Pollution Control Research Series.

______. 14010 SPZ 09/71. Concentrated Mine Drainage Disposal Into Sewage Treatment Systems. September, 1971. Water Pollution Control Research Series.

______. 14010 ECC 08/71. Effects of Various Gas Atmospheres on the Oxidation of Coal Mine Pyrites. August, 1971. Water Pollution Control Research Series.

________. 14010 DYI 02/71. Evaluation of a New Acid Mine Drainage Treatment Process. February, 1971. Water Pollution Control Research Series.

________. 14010 DRB 05/71. Flocculation and Clarification of Mineral Suspension. May, 1971. Water Pollution Control Research Series.

________. 14010 DAY 06/71. Inorganic Sulfur Oxidation by Iron-Oxidizing Bacteria. June, 1971. Water Pollution Control Research Series.

________. 04010 ENW 09/71. Micro-Biological Treatment of Acid Mine Drainage Waters. September, 1971. Water Polltuion Control Research Series.

________. ORD-14010 DYH 12/71. Neutradesulfating Treatment Process for Acid Mine Drainage. December, 1971. Water Pollution Control Research Series.

________. Division of Field Investigation, Denver Center. Pollution Affecting Water Quality of the Cheyenne River System, Western South Dakota. September, 1971.

________. 14010 EIZ 12/71. Studies of Limestone Treatment of Acid Mine Drainage. Part II. December, 1971. Water Pollution Control Research Series.

________. 14010 FNQ 02/72. Electro-Chemical Treatment of Acid Mine Waters. February, 1972. Water Pollution Control Research Series.

________. National Environmental Research Center. Evaluation of Bulkhead Seals. R. B. Scott. October, 1972.

________. 14010 FQR 03/73. Reverse Osmosis Demineralization of Acid Mined Drainage. March, 1972. Water Pollution Control Research Series.

________. 14010 EFK 06/72. Use of Laytex as a Soil Sealant to Control Acid Mine Drainage. June, 1972. Water Pollution Control Research Series.

________. EPA-670/2-73-092. Abatement of Mine Drainage Pollution by Underground Precipitation. Stoddard, C. K. October, 1973. Environmental Protection Technology Series.

________. EPA-670/2-73-100. Applications of Reverse Osmosis to Acid Mine Drainage Treatment. Wilmoth, R. C. December, 1973. Environmental Protection Technology Series.

________. EPA-R2-73-230. Control of Mine Drainage from Coal Mine Mineral Wastes. Kosowski, Z. Z. May, 1973. Environmental Protection Technology Series.

________. EPA-R2-73-169. Dewatering of Mine Drainage Sludge. Akers, E. J. and Moss, E. A. February, 1973. Environmental Protection Technology Series.

________. EPA-R2-73-151. Feasibility Study: Lake Hope Mine Drainage Demonstration Project. March, 1973. Environmental Protection Technology Series.

________. EPA-R3-73-032. Fish and Food Organisms in Acid Mine Waters of Pennsylvania. R. L. Butler, et al. February 1973. Ecological Research Series.

________. EPA-430/9-73-012. Groundwater Pollution From Some Surface Excavations. 1973.

________. EPA-R2-73-135. Investigation of Use of Gel for Mine Sealing. Chung, N. K. January, 1973. Environmental Protection Technology Series.

________. EPA-670/2-73-081. Laboratory Study of Self Sealing Limestone Plugs for Mine Openings. Penrose, R. G. and Holubec, I. September, 1973. Environmental Protection Technology Series.

________. EPA-430/9-73-011. Processes Procedures, and Methods to Control Pollution from Mining Activities. October, 1973.

________. National Field Investigation Center, Denver, Colorado. Reconnaisance Study of Radio Chemical Pollution from Phosphate Rock Mining and Milling. December, 1973.

________. EPA-670/2-73-080. Removal of Heavy Metals from Mine Drains by Precipitation. Ross, L. W. September, 1973. Environmental Protection Technology Series.

________. National Environmental Research Center. Sealing of Coal Refuse Piles. R. B. Scott. July, 1973.

________. National Environmental Research Center. Sodium Hydroxide Treatment of Acid Mine Drainage. J. L. Kennedy. February, 1973.

________. Region X-3. Water Quality Considerations for the Metal Mining Industry In the Pacific Northwest. Sceva, J. E. 1973.

________. EPA-670/2-74-009. Analysis of Pollution Control Costs. Doyle, F. J., et. al. February, 1974. Environmental Protection Technology Series.

________. EPA-670/2-74-001. Carbonate Bonding of Taconite Tailings. La Rosa, P. J. et al. January, 1974. Environmental Protection Technology Series.

________. EPA-670/2-74-023. Electro-Chemical Removal of Heavy Metals from Acid Mine Drainage. Franco, M. B. and Baloufkusra. May, 1974. Environmental Protection Technology Series.

________. EPA-670/2-74-093. Environmental Protection In Surface Coal Mining of Coal. Grim, E. C., Hill, R. D. October, 1974.

________. PB 241247. Environmental Surveys of the Uranium Mill Tailings, Pile, and Surrounding Areas. Salt Lake City, Utah. Office of Radiation Programs for Las Vegas, Nevada. August, 1974.

________. EPA-670/2-74-051. Limestone and Limestone Lime Neutralization of Acid Mine Drainage. Wilmoth, R. C. June, 1974. Environmental Protection Technology Series.

________. EPA-660/3-74-021. Mercury in Aquatic Systems: Methylation, Oxidation-Reduction, and Bioaccumulation. August 1974. Ecological Research Series.

________. EPA-670/2-74-003. Mine Drainage Pollution Control Demonstration Grant Procedures and Requirements. Zaval, F. J. and Burns, R. A. October, 1974. Environmental Protection Technology Series.

________. EPA-670/2-74-070. Mine Spoil Potentials for Soil and Water Quality. Smith, R. M., et al. October, 1974. Environmental Protection Technology Series.

________. EPA-660/2-74-019. North Fork Alluvial Decontamination Project, Hubard Creek Reservoir Watershed. Jacob, B. L. April, 1974. Environmental Protection Technology Series.

________. EPA-660/2/75/038. State-of-the-Art. Uranium Mining, Milling, and Refining Industry. Clark, D. A. June, 1974. Environmental Protection Technology Series.

________. EPA-660/2/74/018. Storage and Disposal of Iron Ore Processing Wastewater. Baillod, C. R. and Alger, P. R. March, 1974. Environmental Protection Technology Series.

________. "User's Handbook for Assessment of Water Pollution From Nonpoint Sources." Midwest Research Institute. December 18, 1974. (Draft)

________. EPA-440/9-75-008. Criteria for Developing Pollution Abatement Programs for Inactive and Abandoned Mine Sites. August, 1975.

________. Development Document for Effluent Limitation Guidelines and Standards of Performance. Mineral, Mining, and Processing Industry. Volume 1. Minerals for the Construction Industry. October, 1975.

________. Development Document for Effluent Limitation Guidelines and Standards of Performance. Mineral, Mining, and Processing Industry. Volume 2. Minerals for the Chemical and Fertilizer Industries. 1975.

________. Development Document for Effluent Limitation Guidelines and Standards of Performance. Mineral, Mining, and Processing Industry. Volume 3. Clay, Ceramic, Refractering, and Miscellaneous Minerals. 1975.

________. EPA-660/3-75-018. Groundwater Pollution Problems in the Northwestern United States. Vander Leden, F. et. al. May, 1975.

________. EPA-440/-75-007. Inactive and Abandoned Underground Mines Water Pollution Prevention and Control. June, 1975.

________. Water Programs, "National Interim Primary Drinking Water Regulations." Federal Register 40, No. 248. December 24, 1975: 59566-59588.

________. Guidelines. "Ore Mining and Dressing Point Source Category." Federal Register 40, No. 215. November 6, 1975: 51722-51748.

________. River Basin Water Quality Status, 1975, Spokane River Basin Profile. Surveillance and Analysis. 1975.

________. EPA-670/2/75/047. Up-dip Versus Down-dip Mining and Evaluation. Mentz, J. W. and Warg, J. B. June, 1975. Environmental Protection Technology Series.

Virginia State Water Control Board. Feasibility Study: Contrary Creek Mine Drainage Abatement Project. Miorin, A. S., et al. 1974.

Water Newsletter. January 13, 1976.

Williams, J. R., Berndt, H. D. "Sediment Yield Computed With Universal Equation". Journal Hydraulics Division. American Society of Civil Engineers. December, 1972.

Williams, R. E. Acid Mining Drainage in Idaho. University of Idaho, College of Mines. September, 1975.

Wilmoth, R. C., Kennedy, J. L., and Hill, R. D. "Observation on Iron Oxide Rates in Acid Mine Drainage Neutralization Plants." Presented at the Fifth Symposium on Coal Mine Drainge Research, Louisville, Kentucky. October, 1974.

Wixson, D. G. and Chen, H. W. Stream Pollution and the New Lead Belt of Southeast Missouri/ Missouri Water Resources Research Center, University of Missouri, Rolland. August 1970.

APPENDIX A

METRIC CONVERSION

From	To	Multiply By[a]
Hectares	Acres	2.472 E+00
Hectares	Square Miles	8.862 E-03
Kilometres	Miles	6.215 E-01
Litres/Second	Cubic Foot/Sec	3.531 E-02
Litres/Second	Gallon/Min	1.585 E+01
Metric Tons	Ounces (avoirdupois)	3.527 E+04
Metres^3	Yards^3	1.308 E+00
Metric Tons	Ounces (troy)	3.215 E+04
Metric Tons	Tons (long)	1.842 E-01
Metric Tons	Tons (short)	1.102 E+00

[a] The conversion factors are written as numbers greater than one and less than ten. This is followed by the letter E (exponent), a plus or minus sign, and two digits which indicate the power of ten by which the number must be multiplied to obtain the correct value. For example: 3.862 E-03 is 0.003862.

APPENDIX B

ILLUSTRATION OF VARIOUS MINING TECHNIQUES

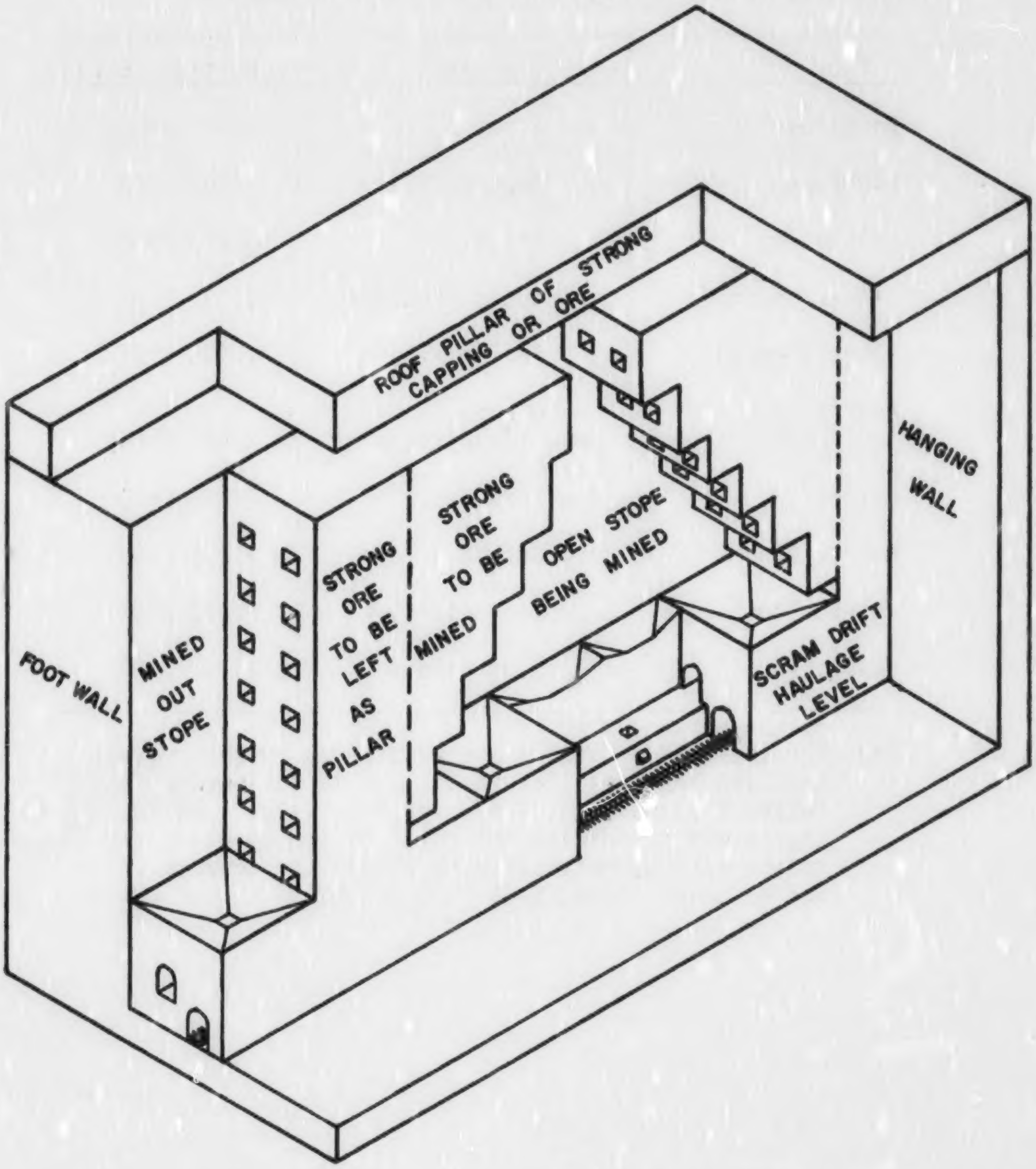

ROOF PILLAR OF STRONG CAPPING OR ORE
HANGING WALL
STRONG ORE TO BE MINED
OPEN STOPE BEING MINED
STRONG ORE TO BE LEFT AS PILLAR
MINED OUT STOPE
FOOT WALL
SCRAM DRIFT HAULAGE LEVEL

Figure B-1. Open stoping sublevel stoping.

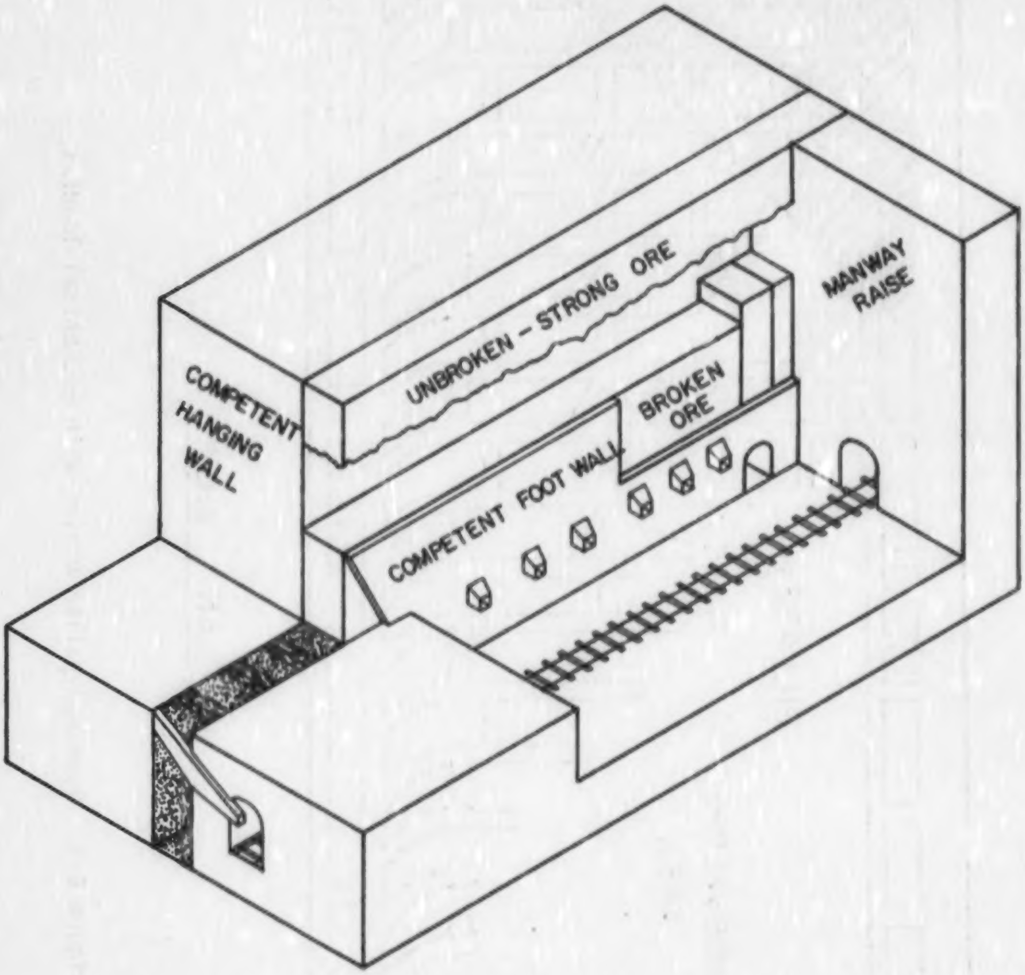
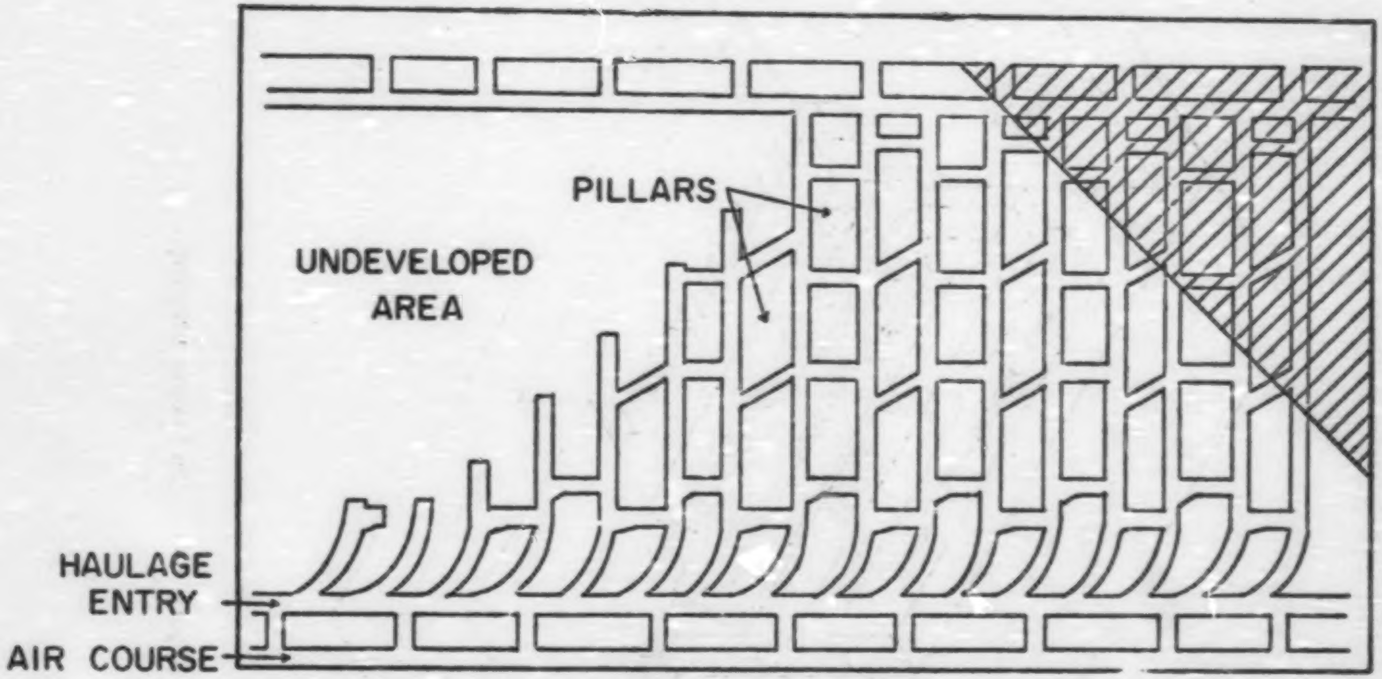

COMPETENT HANGING WALL
UNBROKEN - STRONG ORE
BROKEN ORE
MANWAY RAISE
COMPETENT FOOT WALL

Figure B-2. Shrinkage stoping.


PILLARS
UNDEVELOPED AREA
HAULAGE ENTRY
AIR COURSE

PLAN VIEW

Figure B-3. Room-and-pillar mining with mechanical loaders.

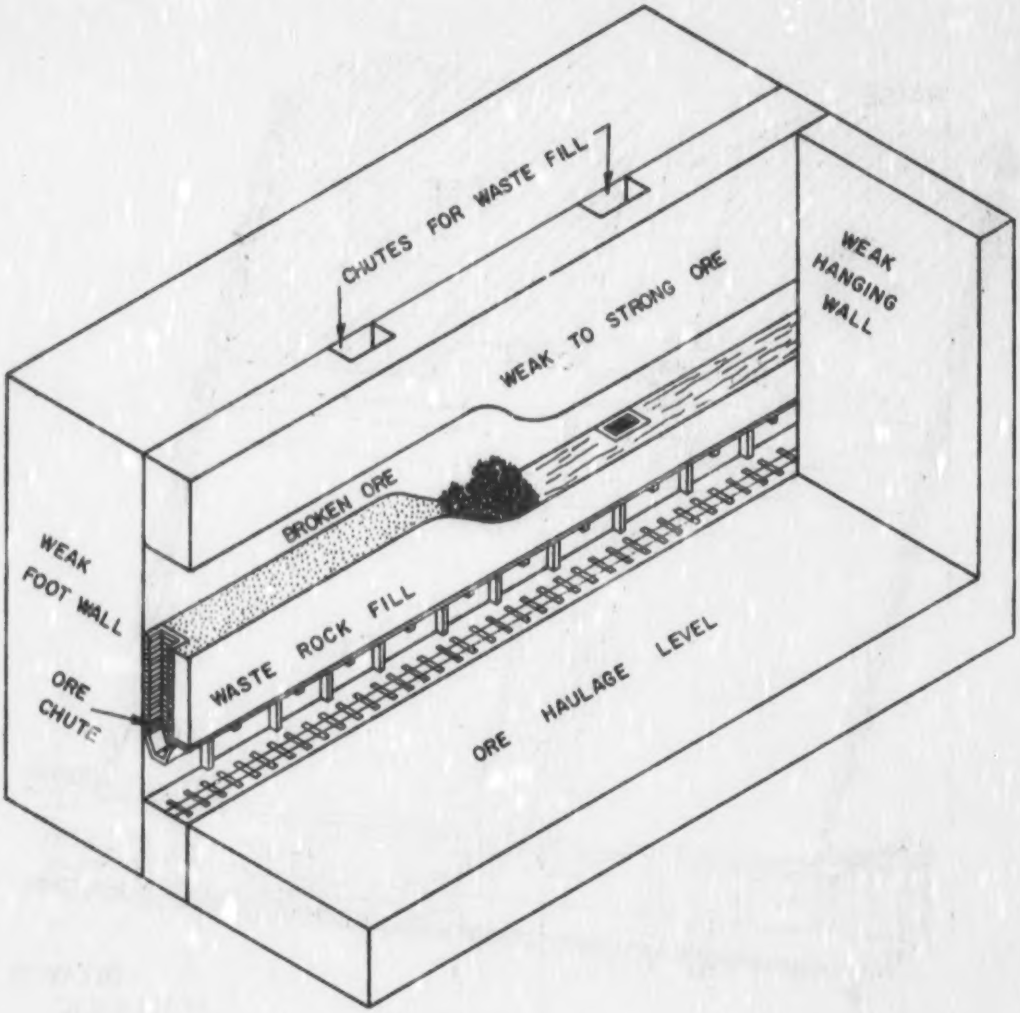

CHUTES FOR WASTE FILL
WEAK HANGING WALL
WEAK TO STRONG ORE
BROKEN ORE
WEAK FOOT WALL
WASTE ROCK FILL
ORE CHUTE
ORE HAULAGE LEVEL

Figure B-4. Cut-and-fill stoping.

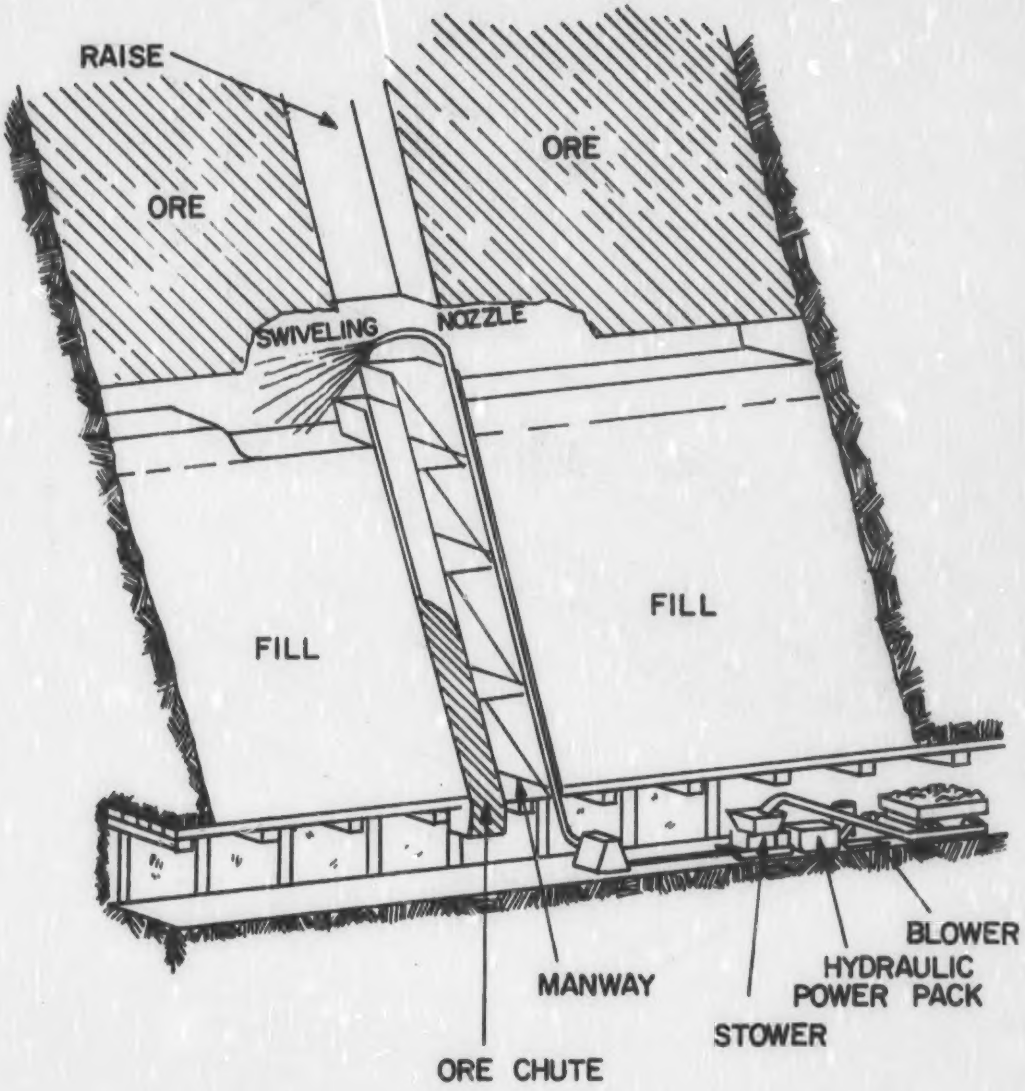
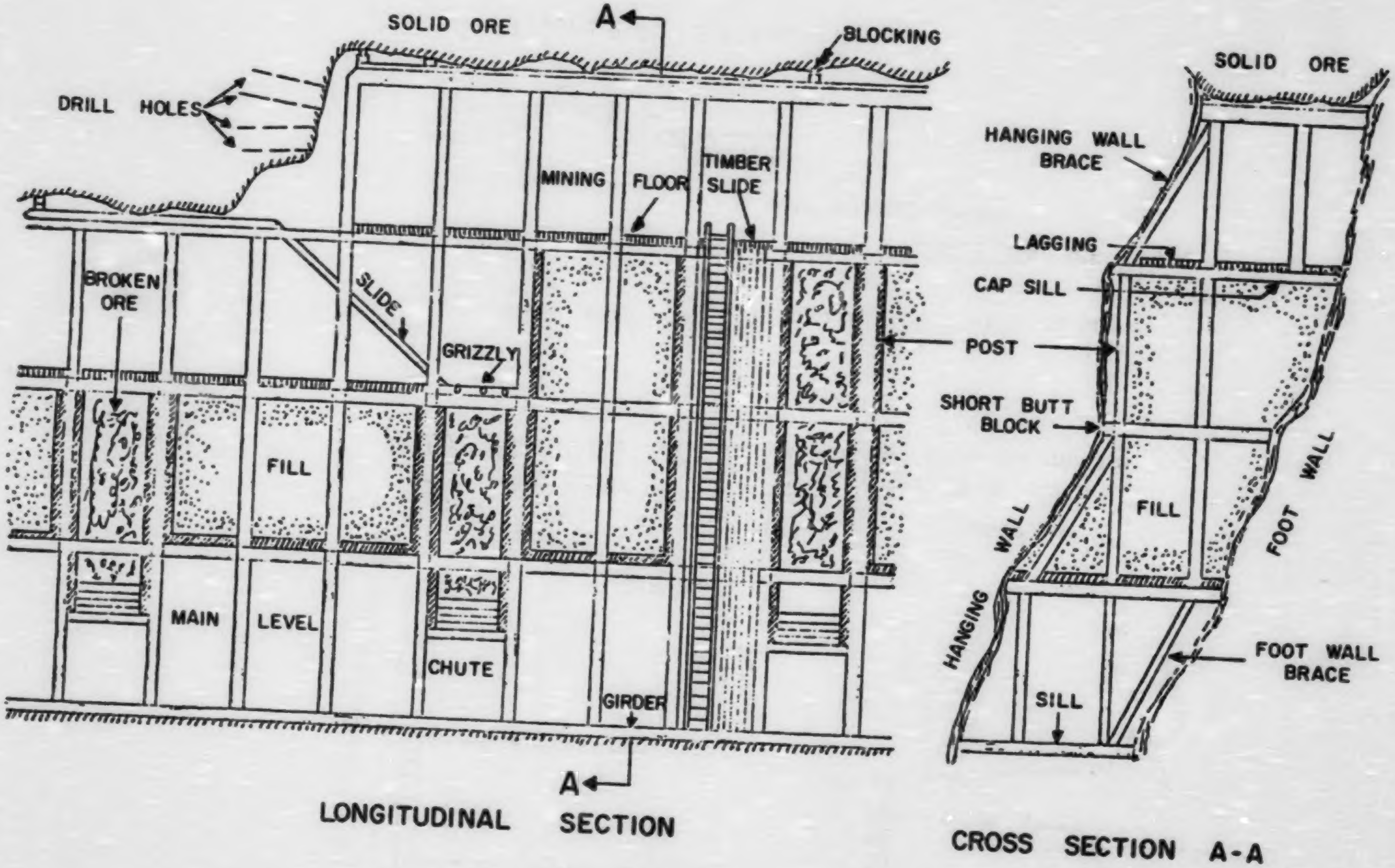

RAISE
ORE
ORE
SWIVELING
NOZZLE
FILL
FILL
BLOWER
HYDRAULIC POWER PACK
MANWAY
STOWER
ORE CHUTE

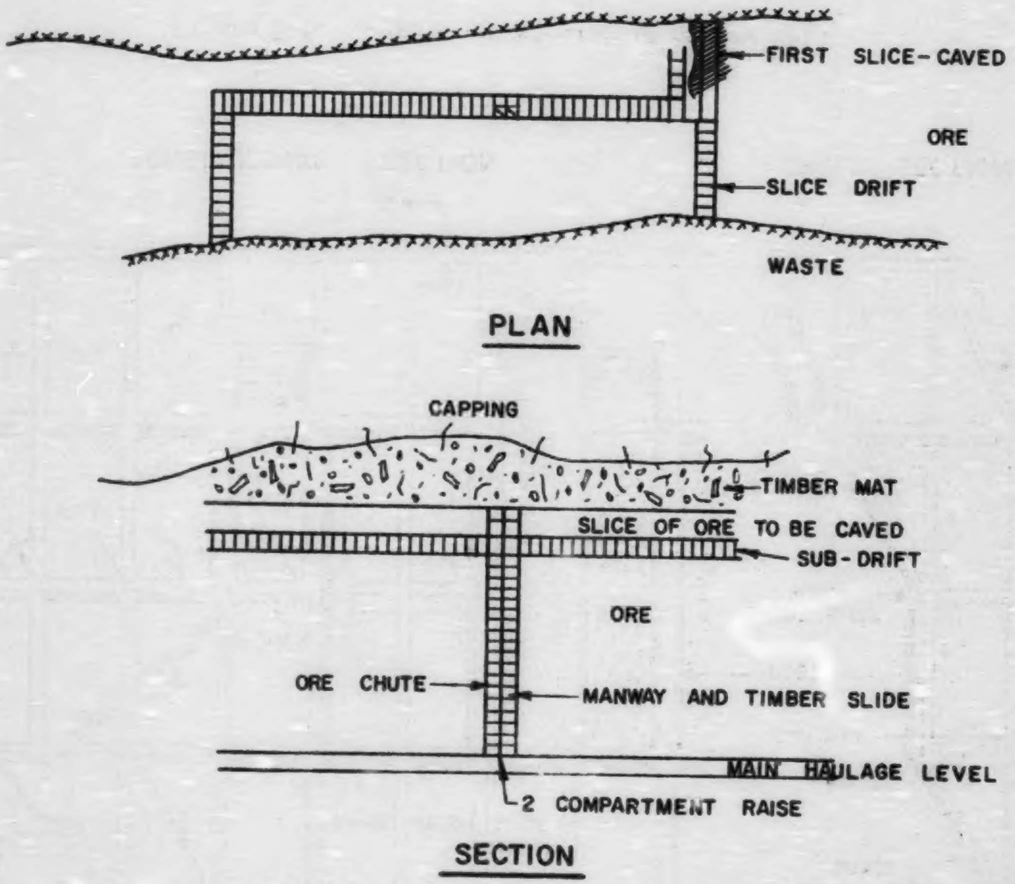
Figure B-5. Cut-and-fill mining with pneumatic backfill system.


LONGITUDINAL SECTION

CROSS SECTION A-A

SOLID ORE
A
BLOCKING
DRILL HOLES
MINING FLOOR
TIMBER SLIDE
BROKEN ORE
SLIDE
GRIZZLY
FILL
MAIN LEVEL
CHUTE
GIRDER
A
SOLID ORE
HANGING WALL BRACE
LAGGING
CAP SILL
POST
SHORT BUTT BLOCK
FILL
FOOT WALL
HANGING WALL
FOOT WALL BRACE
SILL

Figure B-6. Square-set stoping in narrow veins.


FIRST SLICE-CAVED
ORE
SLICE DRIFT
WASTE
CAPPING
TIMBER MAT
SLICE OF ORE TO BE CAVED
SUB-DRIFT
ORE
ORE CHUTE
MANWAY AND TIMBER SLIDE
MAIN HAULAGE LEVEL
2 COMPARTMENT RAISE

PLAN

SECTION

Figure B-7. Sublevel caving.

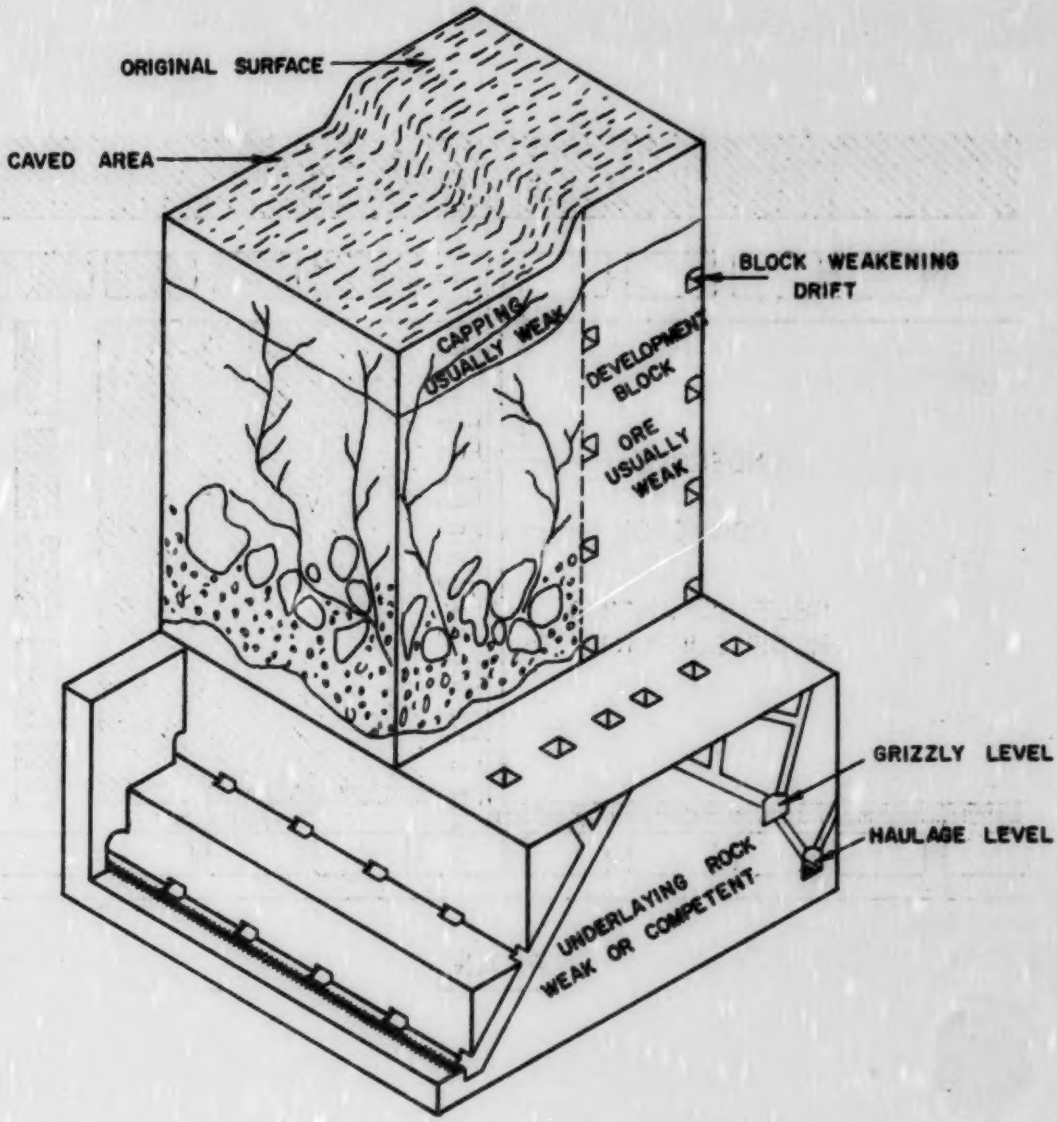

ORIGINAL SURFACE
CAVED AREA
BLOCK WEAKENING DRIFT
CAPPING USUALLY WEAK
DEVELOPMENT BLOCK
ORE USUALLY WEAK
GRIZZLY LEVEL
HAULAGE LEVEL
UNDERLAYING ROCK WEAK OR COMPETENT

Figure B-8. Block caving.

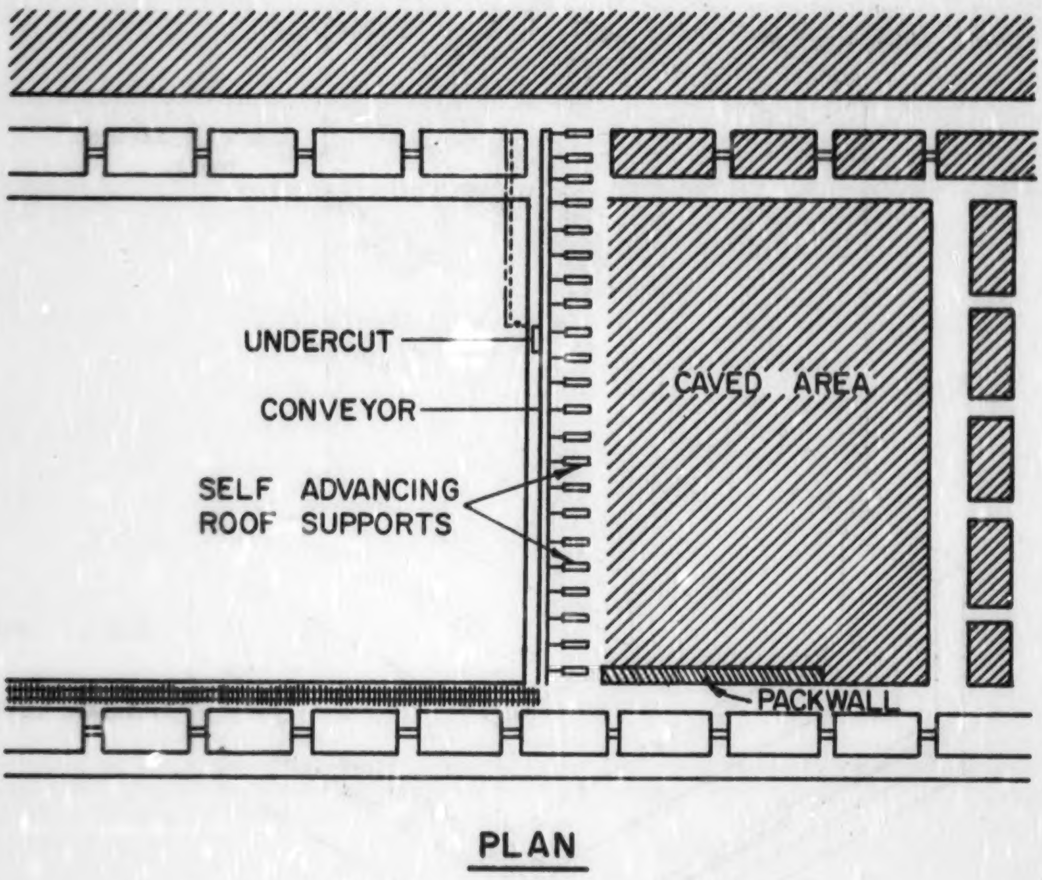

UNDERCUT
CONVEYOR
SELF ADVANCING ROOF SUPPORTS
CAVED AREA
PACKWALL
PLAN

Figure B-9. Longwall mining method.

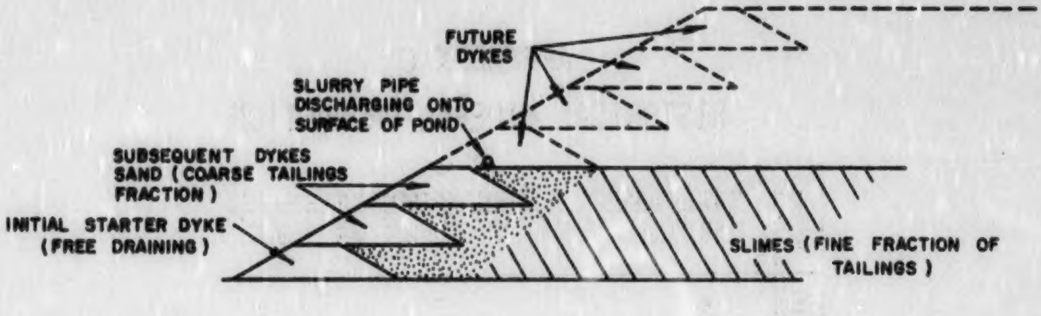

FUTURE DYKES
SLURRY PIPE DISCHARGING ONTO SURFACE OF POND
SUBSEQUENT DYKES SAND (COARSE TAILINGS FRACTION)
INITIAL STARTER DYKE (FREE DRAINING)
SLIMES (FINE FRACTION OF TAILINGS)

Figure B-10. Tailings dam construction U/S method.

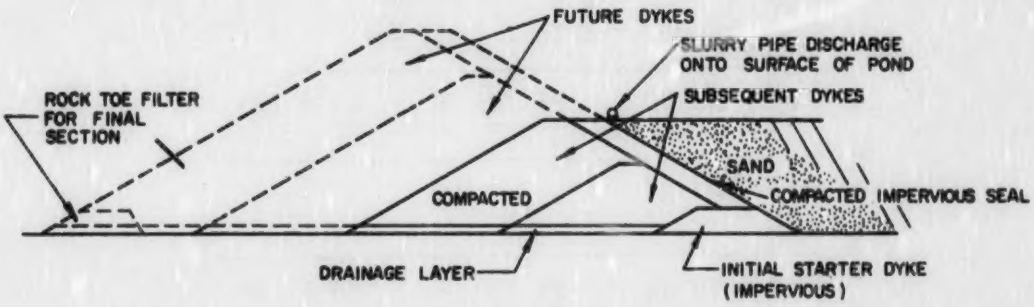

FUTURE DYKES
SLURRY PIPE DISCHARGE ONTO SURFACE OF POND
ROCK TOE FILTER FOR FINAL SECTION
SUBSEQUENT DYKES
SAND
COMPACTED
COMPACTED IMPERVIOUS SEAL
DRAINAGE LAYER
INITIAL STARTER DYKE (IMPERVIOUS)

Figure B-11. Tailings dam construction D/S method.

APPENDIX C
HISTORICAL MINERAL PRODUCTION

TABLE C-1. HISTORIC METAL PRODUCTION BY STATES [a]

State Production Data	Copper 1845-1973	Lead 1873-1973	Mercury 1850-1973	Zinc 1873-1973	Iron 1834-1973	Gold[b] 1792-1973	Silver[b] 1845-1973	Molybdenum[c] 1914-1973	Tungsten[d] 1900-1973	Uranium[e] 1957-1973	Tailings
Alabama	>0.1				313,832	1.5	0.2				313,934
Alaska	662	23	1			932	2,916		>0.1		131,853
Arizona	24,200	589		1,146		440	13,570	259	1.7	1.8	2,620,782
Arkansas		1.7		24					16.9		4,975
California	590.	224	101	150		3,305	3,802		83.2		333,754
Colorado	315.	2,704		2,178		1,278	24,860	647	10.8		567,703
Connecticut									>0.1		1,200
Delaware											[g]
Florida											[g]
Georgia	1				29,942	27	0.3				31,720
Hawaii											[g]
Idaho	198	6,742	1	2,647	1	260	29,300		6.7		547,882
Illinois		117		1,280			5				37,873
Indiana											[g]
Iowa		0.5		0.6							41
Kansas		589		3,172							108,730
Kentucky		17		68				0.300			2,521
Louisiana											[g]
Maine				44							1,090
Maryland						0.2	>0.1				12
Massachusetts											[g]
Michigan	5,675				897,778	1.0	577				1,467,474
Minnesota					3,609,409						3,609,409
Mississippi											[g]
Missouri	113	11,660		2,510			424		>0.1		698,578
Montana	8,079	771		2,526		557	27,357		0.2		1,043,894
Nebraska											[g]
Nevada	3,398	487	6	451		951	19,011		16.5		508,971
New Hampshire											[g]
New Jersey				3,884	46,555						143,660
New Mexico	3,403	286		1,324		73	5,154	36	>0.1	101.5	439,507
New York		43		1,889	167,049		42				217,373
North Carolina	56					37	28		1.8		8,400

(Continued)

TABLE C-1. HISTORIC METAL PRODUCTION BY STATES (Continued)

State Production Data	Copper 1845-1973	Lead 1873-1973	Mercury 1850-1973	Zinc 1873-1973	Iron 1834-1973	Gold[b] 1792-1973	Silver[b] 1845-1973	Molybdenum[c] 1914-1973	Tungsten[d] 1900-1973	Uranium[e] 1957-1973	Tailings
North Dakota											[g]
Ohio											[g]
Oklahoma		1,184		4,733							177,500
Oregon	13	0.6	3.7			180	170		>0.1		13,670
Pennsylvania				359	30,299	1.2	6.4				39,371
Rhode Island											[g]
South Carolina	>0.1					9.9	1.1				618
South Dakota	0.1	0.5				1,103	405		0.6		69,854
Tennessee	621	61		2,639		0.8	157				131,740
Texas	1.3	4.9	4.9	0.8		0.3	1,038		>0.1		5,155
Utah	10,240	4,928		1,682	105,977	644	27,260		0.1		1,557,530
Vermont						0.1	4.7				24
Virginia		117		702		5.2	2.8				23,730
Washington	111	251		572		95.0	420.		0.6		45,450
West Virginia											[g]
Wisconsin		117		1,138	59,821						94,101
Wyoming	15				88,483	2.6	2.3			54.5	102,661
Other								352		95.2	
Total Above	57,091	30,923	118	35,119	5,350,000	10,000	157,000	1,294	139	253	15,000,000
TOTAL U.S. [f]	57,800	30,900	120	35,300	5,420,000	10,000	153,000	1,294	140	253	15,000,000

[a] In thousands metric tons unless otherwise noted. Data based on U.S. Bureau of Mines Mineral yearbooks.
[b] Metric tons.
[c] State figures based on percent production of U.S. total.
[d] Some state figures based on averages.
[e] As U_3O_8. No data available on production prior to 1957.
[f] U.S. totals differ due to inconsistencies in state reporting procedures.
[g] Negligible.

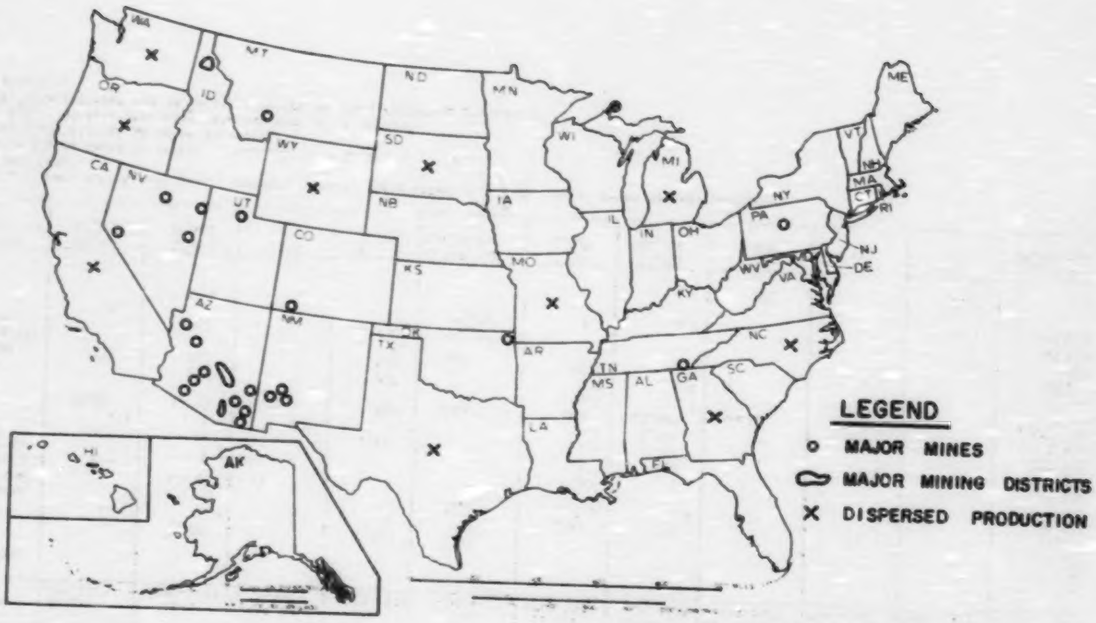

WA
OR
CA
NV
ID
MT
WY
UT
CO
AZ
NM
ND
SD
NB
KS
OK
TX
MN
IA
MO
AR
LA
WI
IL
MI
IN
OH
KY
TN
MS
AL
GA
FL
SC
NC
VA
WV
PA
NY
VT
NH
ME
MA
CT
RI
NJ
DE
HI
AK
LEGEND
o MAJOR MINES
MAJOR MINING DISTRICTS
X DISPERSED PRODUCTION

Figure C-1. Geographical distribution of mineral production - Copper.

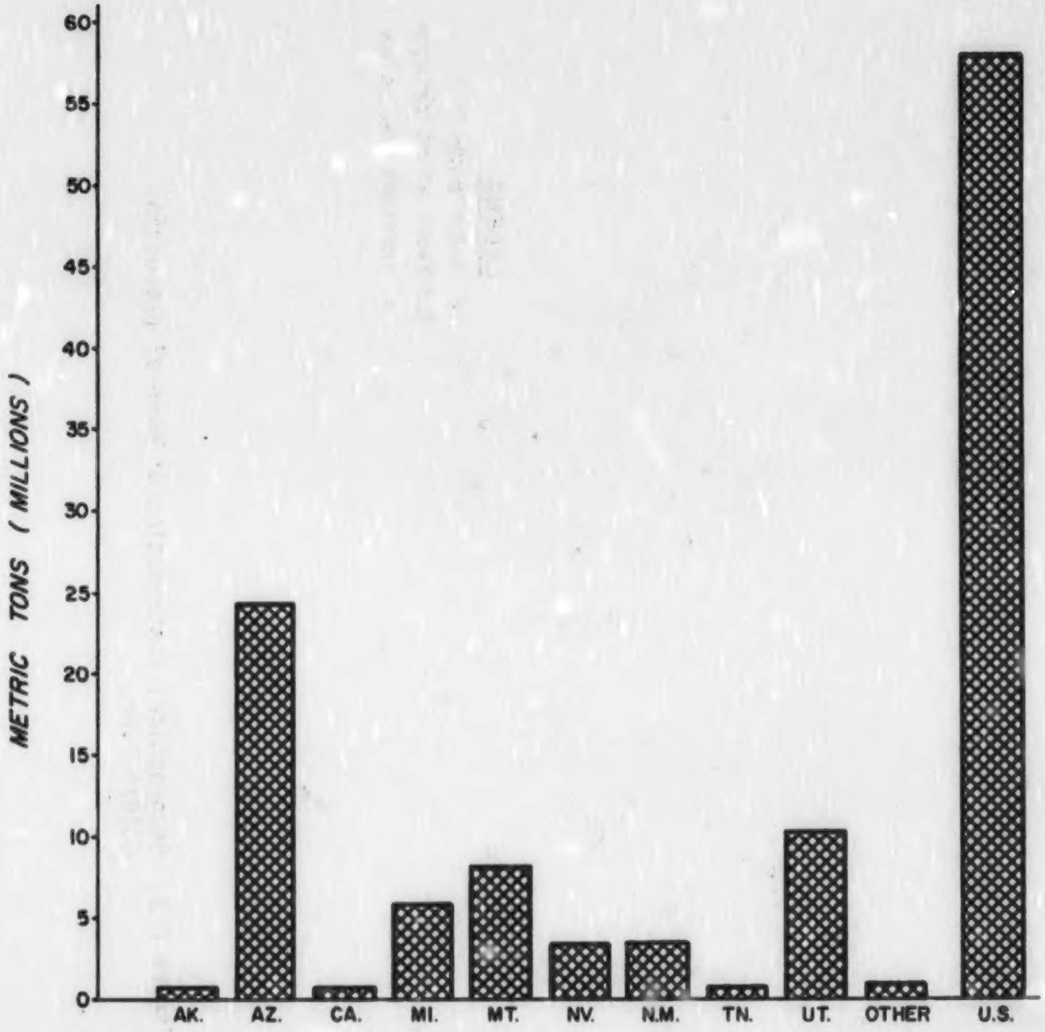


Figure C-2. Historical production - Copper.

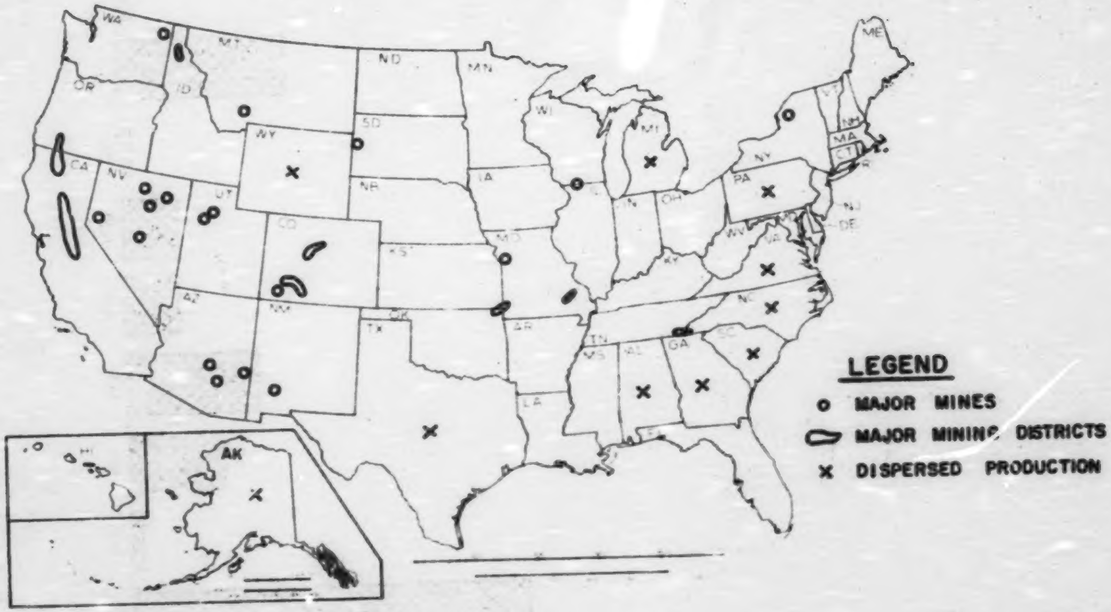
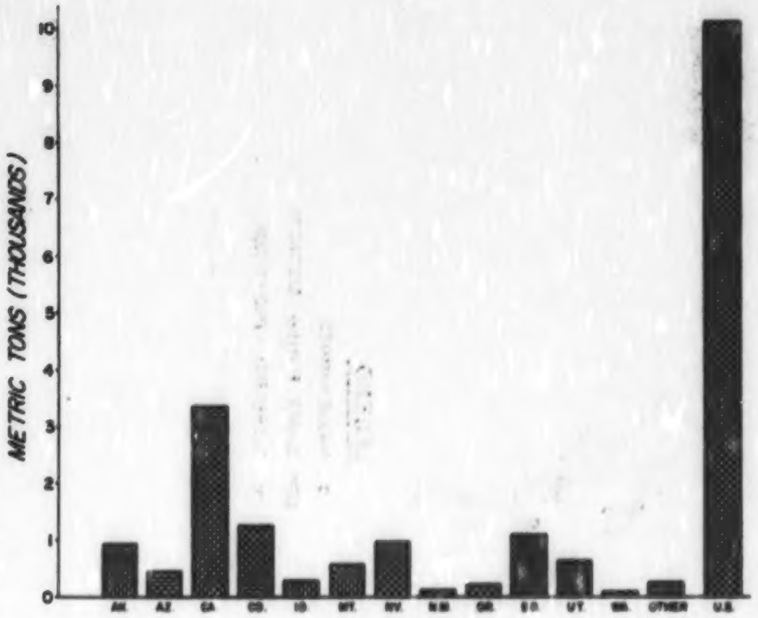
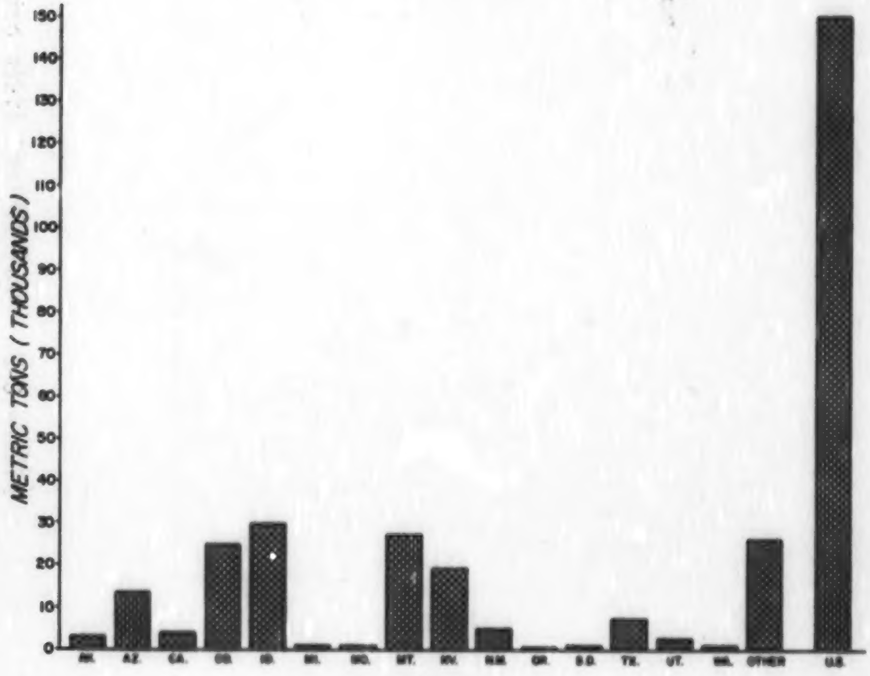

WA
OR
CA
NV
ID
MT
WY
UT
AZ
CO
NM
ND
SD
NB
KS
OK
TX
MN
IA
MO
AR
LA
WI
IL
MI
IN
OH
KY
TN
MS
AL
GA
FL
SC
NC
VA
WV
PA
NY
VT
NH
ME
MA
CT
RI
NJ
DE
AK
HI
LEGEND
o MAJOR MINES
MAJOR MINING DISTRICTS
x DISPERSED PRODUCTION

Figure C-3. Geographical distribution of mineral production - Gold/Silver.



Gold



Silver

Figure C-4. Historical production

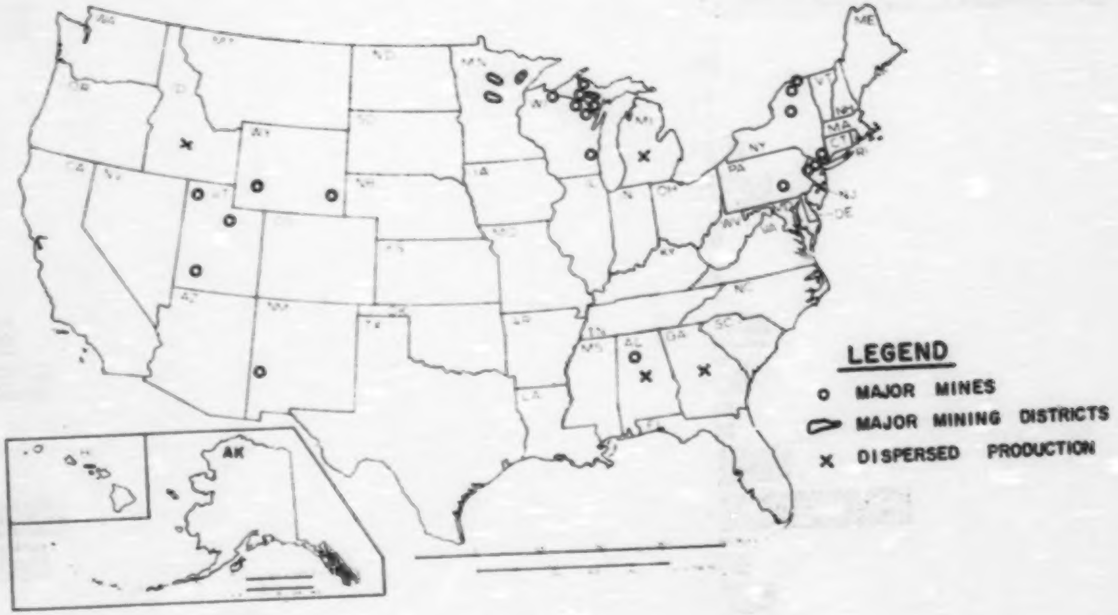

LEGEND
o MAJOR MINES
MAJOR MINING DISTRICTS
x DISPERSED PRODUCTION
AK
ME
VT
NH
MA
CT
RI
NY
PA
NJ
DE
MI
WI
MN
AL
GA
SC
NC

Figure C-5. Geographical distribution of mineral production - Iron Ore.

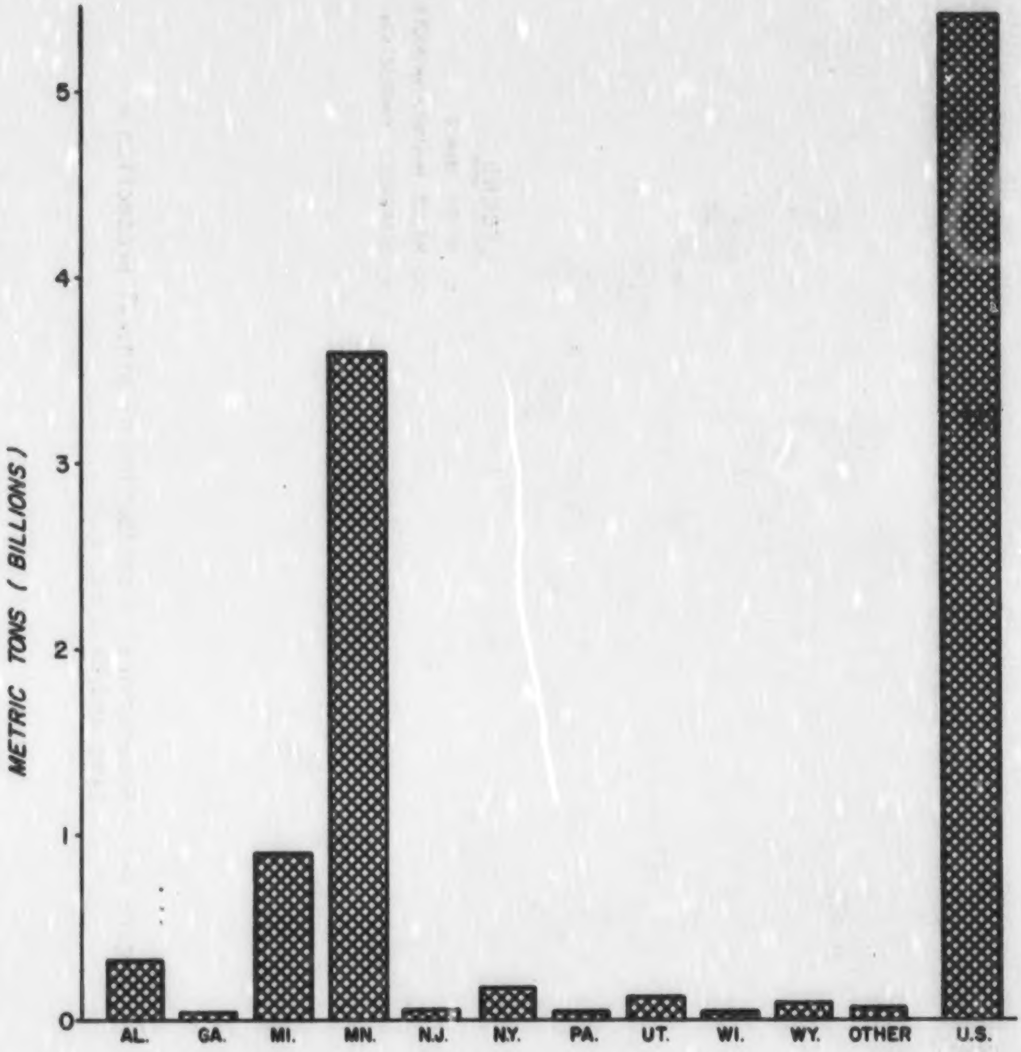


Figure C-6. Historical production - Iron Ore.

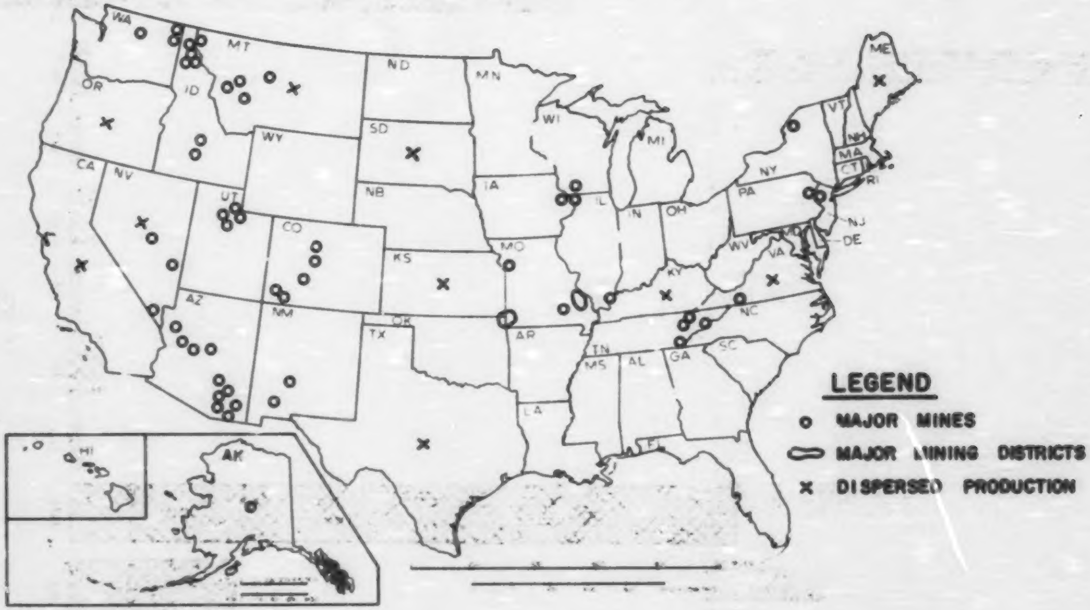
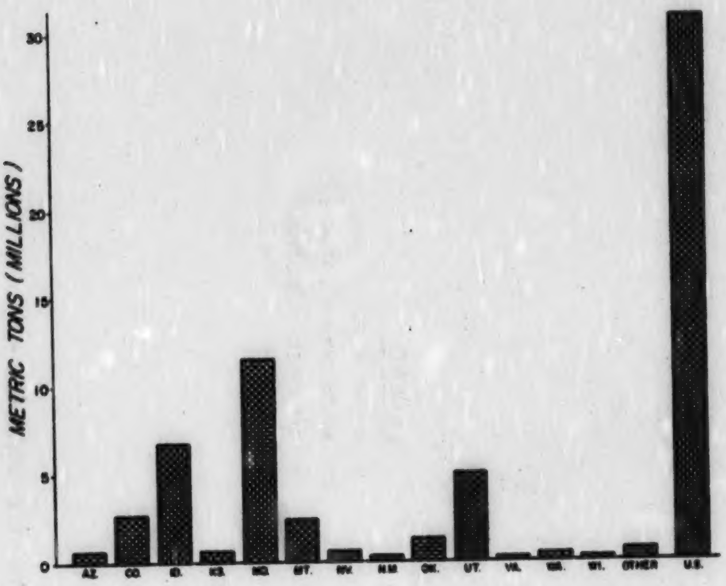
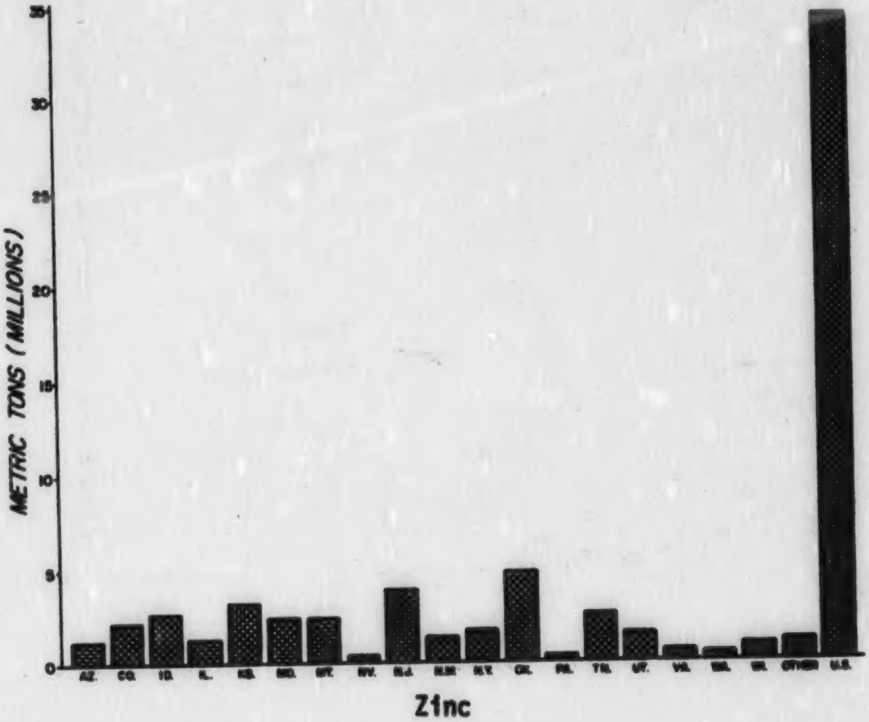

WA
OR
CA
NV
ID
MT
WY
UT
AZ
CO
NM
ND
SD
NB
KS
OK
TX
MN
IA
MO
AR
LA
WI
IL
MI
IN
OH
KY
TN
MS
AL
GA
FL
SC
NC
VA
WV
MD
PA
NY
NJ
DE
VT
NH
MA
CT
RI
ME
HI
AK
LEGEND
o MAJOR MINES
⊂⊃ MAJOR MINING DISTRICTS
x DISPERSED PRODUCTION

Figure C-7. Geographical distribution of mineral production - Lead and/or Zinc.



Lead



Zinc

Figure C-8. Historical production

Reproduced from
best available copy.

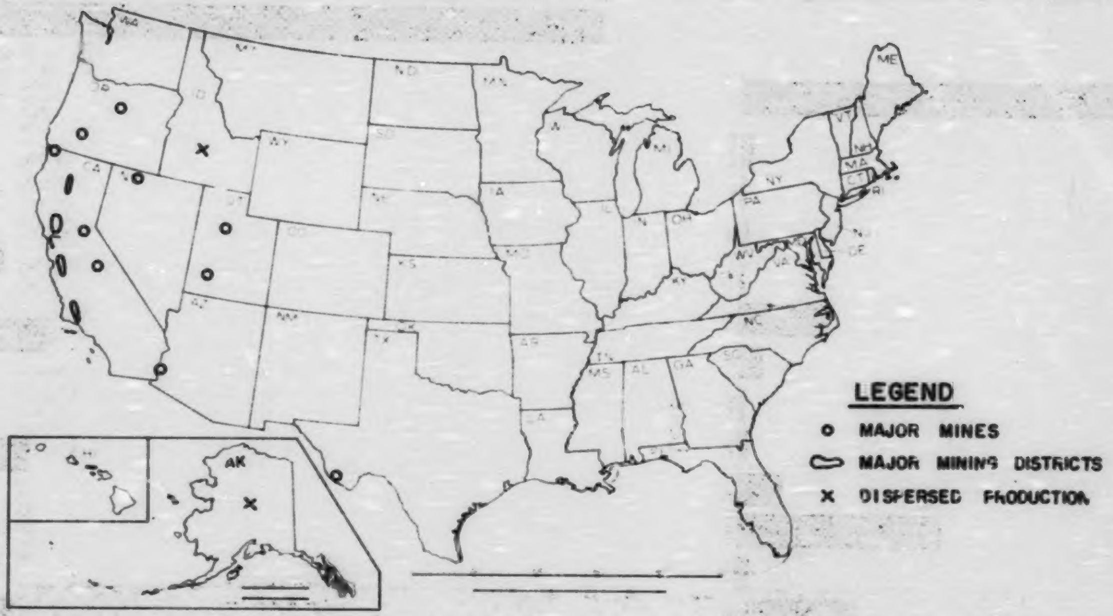

LEGEND
o MAJOR MINES
⬭ MAJOR MINING DISTRICTS
× DISPERSED PRODUCTION
WA
OR
CA
NV
ID
MT
WY
UT
AZ
NM
CO
ND
SD
NE
KS
OK
TX
MN
IA
MO
AR
LA
WI
IL
MI
IN
OH
KY
TN
MS
AL
GA
FL
SC
NC
VA
WV
MD
PA
NY
NJ
DE
CT
RI
MA
VT
NH
ME
AK

Figure C-9. Geographical distribution of mineral production - Mercury.

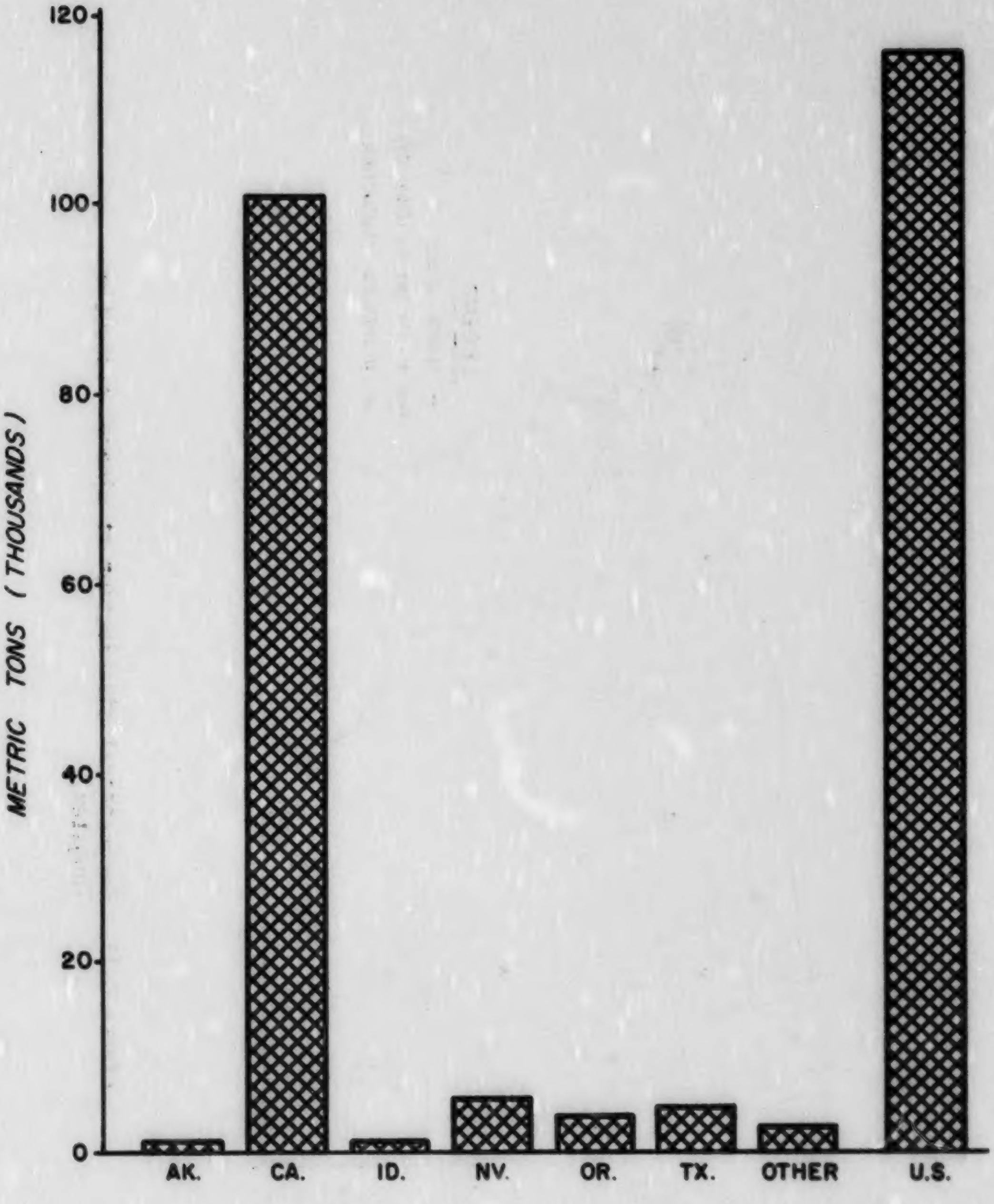
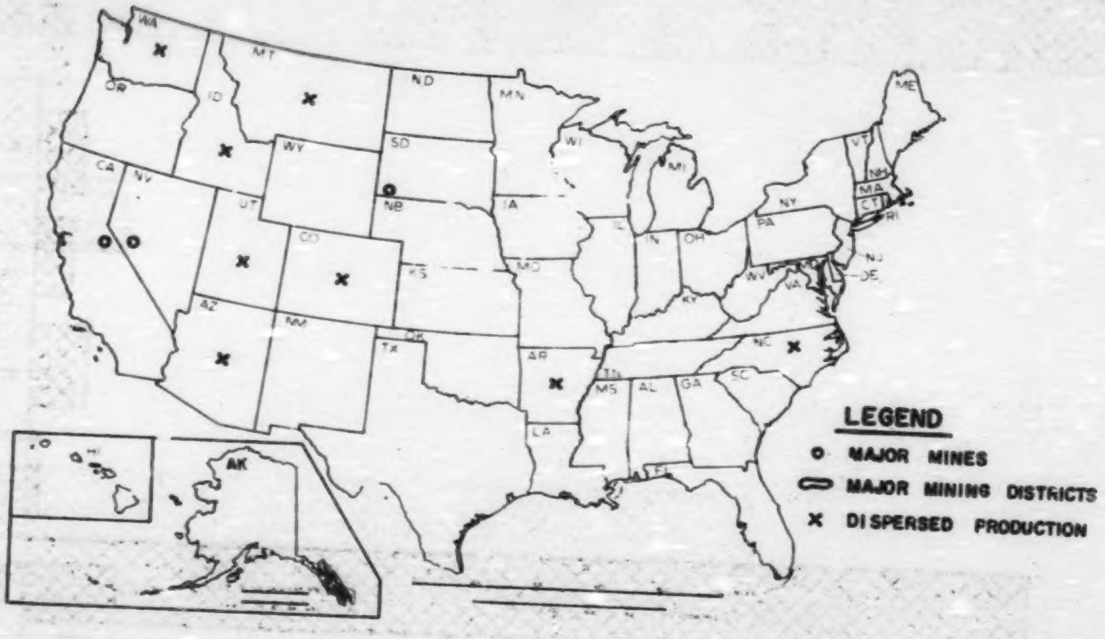


Figure C-10. Historical production - Mercury.



WA
OR
CA
NV
ID
MT
WY
UT
AZ
CO
NM
ND
SD
NB
KS
OK
TX
MN
IA
MO
AR
LA
WI
MI
IL
IN
OH
KY
TN
MS
AL
GA
FL
SC
NC
VA
WV
PA
NY
VT
NH
ME
MA
CT
RI
NJ
DE
HI
AK
LEGEND
MAJOR MINES
MAJOR MINING DISTRICTS
DISPERSED PRODUCTION

Figure C-11. Geographical distribution of mineral production - Tungsten.

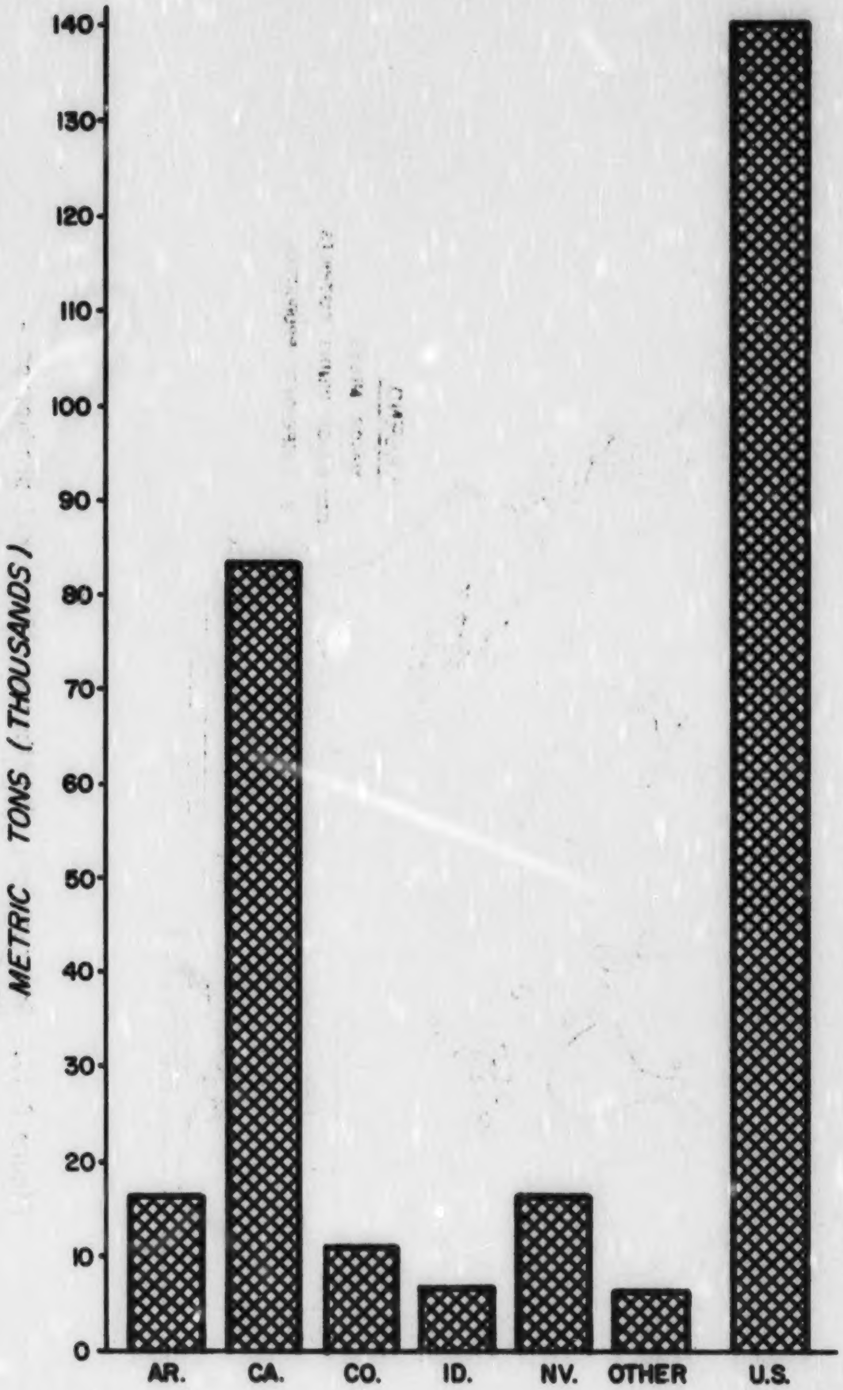


Figure C-12. Historical production - Tungsten.

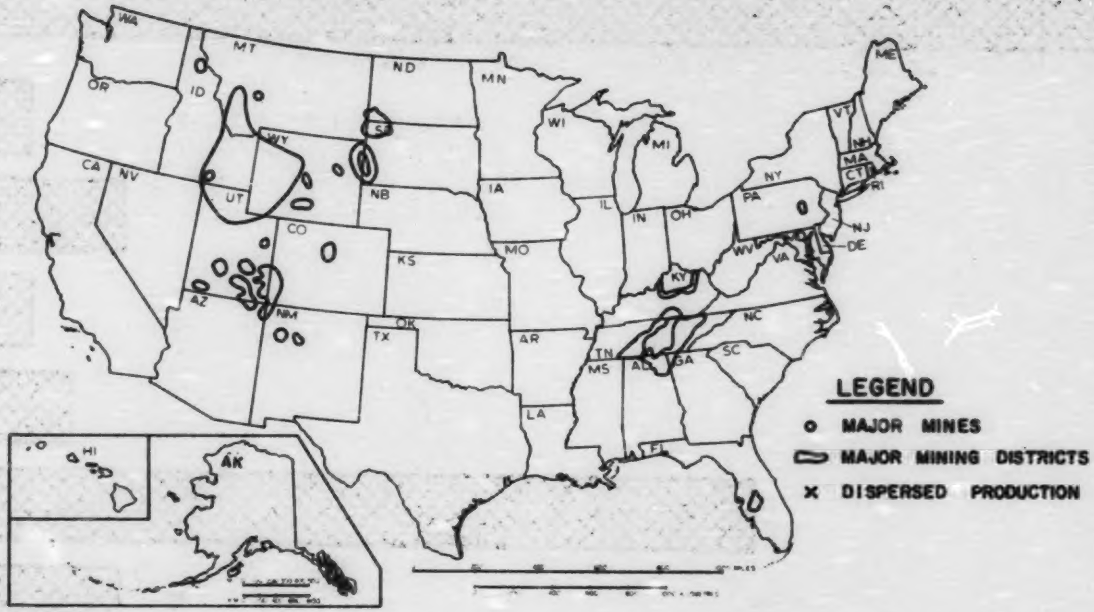

WA
OR
CA
NV
ID
MT
WY
UT
AZ
CO
NM
ND
SD
NB
KS
OK
TX
MN
IA
MO
AR
LA
WI
IL
MI
IN
OH
KY
TN
MS
AL
GA
FL
SC
NC
VA
WV
PA
NY
VT
NH
ME
MA
CT
RI
NJ
DE
HI
AK
LEGEND
o MAJOR MINES
MAJOR MINING DISTRICTS
x DISPERSED PRODUCTION

Figure C-13. Geographical distribution of mineral production - Uranium.

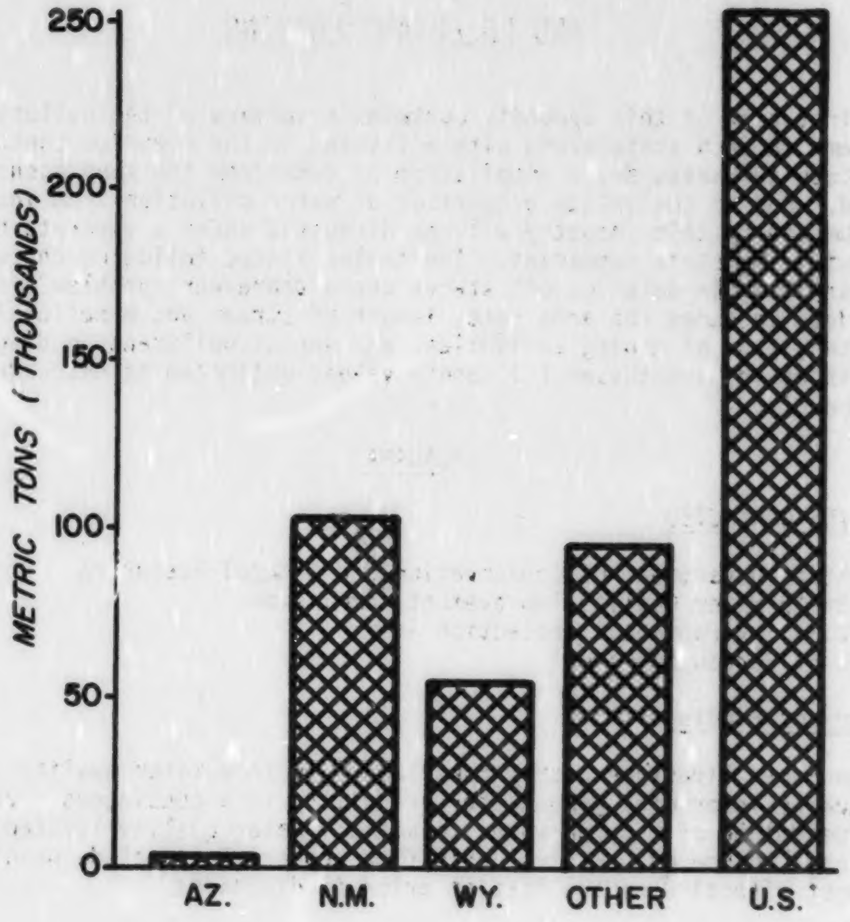


Figure C-14. Historical production - Uranium.

APPENDIX D

STATE ASSESSMENTS OF PROBLEM AREAS AND POLLUTANT LOADING

The first part of this appendix contains a summary of the pollution problems in each state along with a listing of the agencies contacted. The state summaries are a compilation of data from the many agencies listed. Due to the unique properties of water pollution from inactive uranium mines, this industry will be discussed under a separate heading following the state summaries. The tables listed following the uranium industry contain data for all states where there were problem areas. This data includes the area name, length of stream and beneficial uses affected, type of mining activities, and annual pollutant loading. Quantities in parentheses ( ) denote values estimated as discussed in Section 6.

ALABAMA

AGENCIES CONTACTED

- State Department of Conservation and Natural Resources
- State Water Quality Improvement Commission
- U.S. Environmental Protection Agency
- U.S. Bureau of Mines

Summary of Findings

An abandoned limestone quarry contributes surface water quality problems. The quarry intersects groundwater, resulting in a continuous overflow of a large volume of high pH water to a small water quality limited stream. The large volume of uncontrollable flow appears to preclude practical and cost-effective neutralization prior to discharge.

ALASKA

AGENCIES CONTACTED

- Alaska Department of Environmental Conservation
- U.S. Bureau of Land Management
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service
- U.S. Forestry Service

Summary of Findings

No specific problems were reported by the agencies contacted. However, in a report prepared by the Federal Water Pollution Control Administration, it was found that dredging operations in alluvial streams have caused changes in streambed gradients. Mining on Cripple Creek at Dredge Lake was causing erosion of the natural streambed above the lake and increased sediment deposition in the lake. Turbidity of the stream entering the lake was measured at 950 JTU; leaving the lake it was 6 JTU [FWPCA 1969].

This degradation can be expected to continue until the streambed grade reaches equilibrium in the dredged area. No data is available regarding the extent of the problem caused by inactive mines.

ARIZONA

AGENCIES CONTACTED

- ° State Bureau of Water Quality Control
- ° U.S. Bureau of Land Management
- ° U.S. Environmental Protection Agency
- ° U.S. Forestry Service

Summary of Findings

Only mining two locations were reported to affect surface water quality. Metals from the Sheldon and other inactive mines (AZ-1) are suspected of inhibiting fish and other aquatic life, reducing the value of Lynx Lake as a fishery.

Sporadic complaints have been made about water pollution in Patagonia Lake (AZ-2). Discoloration and sedimentation from intermittent flows have been caused by old lead, silver and gold mining operations.

The groundwater in the Globe-Miami Mining District (AZ-3) has been degraded from active and inactive mining operations over the years. High concentrations of TDS and sulfate have limited the use of the groundwater for municipal purposes. No studies were discovered which dealt with the cause and possible cure to this problem.

ARKANSAS

AGENCIES CONTACTED

- ° State Department of Pollution Control and Ecology
- ° U.S. Geological Survey, Water Resources Division
- ° U.S. National Park Service
- ° U.S. Environmental Protection Agency

Summary of Findings

Minor water quality problems have been associated with past mining activity. Two old lead and zinc mining districts, the Rush-Moumee and Ponca-Boxleg Districts (AK-1), are suspected of causing high heavy metal concentration in the benthic muds of the Buffalo National River. High concentrations of lead, zinc, and cadmium have been reported as a result of erosion and sedimentation of tailings. However, analyses of river water samples indicate that little metal is being dissolved.

Past barite mining in the Magnet Cove District (AK-2) is reportedly causing minor turbidity and high TDS concentrations in the waters in Cove Creek, a tributary of the Ouachita River.

The Bauxite Mining District (AK-3), drained by tributaries of the Saline and Ouachita Rivers is suspected of mine related acid drainage. No specific mines have been identified as the source of pollution.

CALIFORNIA

AGENCIES CONTACTED

- State Water Quality Control Board (Nine regional offices)
- State Water Resources Control Board
- State Division of Mines and Geology
- U.S. Geological Survey
- U.S. Fish and Wildlife Service
- U.S. Forestry Service
- U.S. Bureau of Land Management

Summary of Findings

The water quality in 89 kilometres of streams has been degraded by mine drainage from eight mines or mining areas (CA 1-8). The degradation ranges from complete sterility to limited aquatic diversity. The data available on these mines is relatively complete.

An additional 18 mines (CA 9-26) have been cited as known or suspected sources of intermittent dischargers of poor quality water. The impact of these mines on receiving water quality is limited and data is sparse.

Drainage from the adit at the Grey Eagle (CA-1) Mine has been diverted and no longer discharges directly into Indian Creek. However, the creek is degraded by low pH water and high metals concentration. Natural deposits may be the source of this low quality water.

Mercury concentrations have been noted in fish tissue below the Almaden Mine (CA-2), as a result of high concentrations of mercury in the stream sediments. The source of the mercury is probably from metal that escaped during active operation rather than erosion of tailings since little mercury is expected to be found in the tailings of a mercury mine which mainly consist of waste rock and retort slag.

The Buena Vista Mine (CA-3) is located in a geo-chemically reactive area. Heavy iron oxide cementation of river gravels in old stream terraces downstream from the mine appear to indicate that the mine area has been producing acid and the associated iron hydroxide precipitate long before any mining activity. Undoubtedly this process has been accelerated by the mining operations. Corrective measures attempted include covering the slag heap with a clay blanket, sprinkler spreading of acid water, addition of limestone to neutralize acid water, and construction of evaporation ponds. All of these efforts have had little or no success as long-range solutions.

The Penn Mine (CA-6) has been reported to affect only 3 kilometres of the Mokelumne River. This may be misleading. The mine is approximately 3 kilometres up river from Comanche Reservoir where mine wastes apparently have no effect on aquatic life. However, it is suspected that copper deposited in the benthic muds is reduced to a more soluble form by anaerobic organisms. Subsequent discharges of this water have adversely affected the spawning success of the salmon and steelhead hatchery downstream [CRWQB 1971].

Lake Berryessa has a limited area of spawning gravels located in James and Pope Creeks, which drain the Corona Mine (CA-7). The discharge of acid from the Corona Mines assumes the controlling influence in the perpetuation of the trout fishery, however, the water quality in the remainder of the lake appears unaffected by the mine [CRWQB 1961].

The streams in the Shasta District area (CA-8) drain into Lake Shasta and Keswick Reservoir. Approximately 18 kilometres of these streams have been adversly affected by the many mines in the district. The magnitude of the problem is exemplified by the number of fish kills. Since 1965 there have been fifteen incidents of fish kills with over 59,000 fish reportedly killed at seven locations.

In summary, the most severely impacted beneficial use is depressed or no aquatic life. In addition to the eight serious locations (map reference CA 1-8), fishing and fish populations have been affected at nine other locations. Many of the minor problem areas are the result of ephemeral discharges, which complicates documentation of the problems since the flows are not continuous and are less predictable. Spring freshets occurring below the Greenhorn (CA-13), Engle (CA-14, Reed (CA-17), and Mt. Diablo (CA-26) Mines have been recognized as a threat to sport fisheries [CRWQB 1971].

COLORADO

AGENCIES CONTACTED

- ° State Department of Health
- ° U.S. Geological Survey
- ° U.S. Environmental Protection Agency

- U.S. Bureau of Mines
- U.S. Bureau of Land Management
- U.S. Forestry Service

Summary of Findings

Approximately 675 kilometres of stream have been adversely affected by active and inactive metal mining activities. The following is a summary of the most significant problems in areas where all or a portion of mining activity is inactive. This summary accounts for approximately 486 kilometres of the affected streams [USGS 1974a]. Stream quality is degraded as a result of natural causes and past and present mining and in many instances it is impractical to attempt to segregate the sources of the problem. More realistically, each area will be discussed with attention focused on the activity of mining and natural sources of pollution.

Discharges from the Jamestown, Burlington and Emmit Mines (CO-1) have depressed aquatic life on 14 kilometres of Little James Creek. During 1972 there was limited mining of flourspar.

In the Central City and Idaho Springs area (CO-2, 3 and 4) high metal concentrations have degraded the quality of approximately 100 kilometres of stream system. The area is abundant with many small inactive mines and a few active ones. Stream samples are moderately high in metal concentrations and the pH range is normal. The majority of data available are based on stream samples which indicates an overall stream quality but does not indicate the concentration of particular mine drainage or the overall pollutant loading. An example of the concentration of metals in mine drainage may br seen from data collected from the Argo Tunnel which are as follows: pH 2.8, Fe 140-380 mg/l, Mn 95-150 mg/l and Zn 45-76 mg/l.

In the Urad-Henderson (CO-5) area some sporadic mining still occurs although the Urad Mine was closed in 1974. Although the mine, mill and tailings are on the east slope, there is a drainage tunnel to the west slope which affects the water quality in the Williams Fork and Darling Creek.

The Leadville (CO-6) area was one of the most extensively mined areas of the state. Approximately 110 kilometres of stream have been affected by drainage high in metal concentration. As in the central city area, the concentration of drainage is not reflected by stream quality data. The Yak drainage tunnel has a flow approximately equal to 5 percent of the flow of Arkansas River below Iowa Gulch. Concentrations in the Yak Tunnel are as follows: pH 3-8, Fe 50 mg/l, Cu 1.5 mg/l, Mn 28.0, and Zn 56-100 mg/l.

All of the mines in the Lake Creek (CO-7) and Kerber Creek (CO-8) are inactive. In the Creede area (10-9) a failure in the mill effluent ditch caused a fish kill in the Rio Grande River.

The Summitville Mining District (CO-10) is in a geo-chemically reactive area. Degraded water quality appears to be a result of natural conditions. However, it can be argued that mining activities have accelerated the problem.

Metal concentrations from the Montezuma Mine (CO-11) and the Breckenridge area (CO-12) have limited the aquatic diversity in receiving streams flowing into Dillon Reservoir. The only active mine in these areas is in the Breckenridge area.

In the Crested Butte (CO-13) and Red Mountain (CO-14) areas, there are two active and many inactive mines. Apparently most of the problem at CO-14 is caused by active mines.

CONNECTICUT

AGENCIES CONTACTED

- State Department of Environmental Protection
- U.S. Environmental Protection Agency
- U.S. Geological Survey
- U.S. National Park Survice

Summary of Findings

No water quality problems were reported within the scope of this study.

DELAWARE

AGENCIES CONTACTED

- Department of Natural Resources and Environmental Control
- State Department of Natural Resources and Environmental Control
- U.S. Environmental Protection Agency
- U.S. Bureau of Land Management

Summary of Findings

No water quality problems were reported within the scope of this study.

FLORIDA

AGENCIES CONTACTED

- State Department of Environmental Regulation
- State Game and Fresh Water Fish Commission
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service

Summary of Findings

The phosphate mining areas were frequently mentioned as a possible source of pollution. The montmorillonitic clays associated with the slime produced by phosphate mining readily adsorb water. These hydroscopic slimes occupy vast areas of land in the dewatering process. Erosion of these tailings has caused fish kills. The mining operations are still active although the slime disposal areas may be no longer active and thus are not within the scope of this report.

GEORGIA

AGENCIES CONTACTED

- ° State Department of Natural Resources
- ° Environmental Protection Division
- ° Game and Fish Commission
- ° U.S. Environmental Protection Agency
- ° U.S. Fish and Wildlife Service
- ° U.S. Forestry Service
- ° U.S. Geological Survey, Water Resources Division

Summary of Findings

Past water pollution problems associated with the kaolin mining areas are now under control. No other problems were reported.

HAWAII

AGENCIES CONTACTED

- ° State Department of Health

Summary of Findings

No water quality problems were reported within the scope of this study.

IDAHO

AGENCIES CONTACTED

- ° State Department of Health, Environmental Division
- ° U.S. Environmental Protection Agency
- ° U.S. Forestry Service
- ° U.S. Geological Survey
- ° National Park Service

Summary of Findings

Drainage from a number of mining districts has degraded water quality in excess of 130 kilometres of stream. In some of the areas, it is impractical to attempt to separate active from inactive mining as a source of water quality degradation. This is especially true of the Coeur d'Alene mining district in northern Idaho, and the phosphate mining areas in southeastern Idaho.

Most regions of the state experience some water quality problems due to inactive mine drainage.

The Jack Waite (ID-11) and Continental (ID-12) Mines near the Canadian Border have been identified with significant pollution problems. Drainage containing high concentrations of heavy metals, particularly zinc, has created sterile conditions in approximately 8 kilometres of stream below Jack Waite Mine on Tributary Creek, and 20 kilometres of stream below Continental Mine on Blue Joe Creek.

In northern Idaho, serious water quality degradation occurs in the Coeur d'Alene mining district (ID-4). Approximately 25 inactive mines located in the Coeur d'Alene mining district are the source of acid mine drainage and heavy metal pollution. The Bunker Hill Mine, only part of which is inactive, has been the source of extensive study. It has been identified as a significant contributor to water quality problems in the Coeur d'Alene District. The South Fork of the Coeur d'Alene River is reported to have no fish life due to the many mines in the area, from the mining district for approximately 55 kilometres downstream until the river discharges into Coeur d'Alene Lake.

In Central Idaho a few mines present notable water quality problems. The Blackbird Mine (ID-1) near Cobalt, Idaho is responsible for discharge of waters of high heavy metal content and low pH. Salmon and Steelhead spawning in parts of the Panther Creek drainage system have been eliminated. The Stibnite Mine (ID-2) has long been associated with sediment problems in the East Fork of the South Fork of the Salmon River. However, this condition has reportedly improved in recent years.

The Silver City area (ID-14) in southwestern Idaho was the site of extensive silver and gold mining at the turn of the century. Mercury was used as an amalgam and careless disposal introduced much mercury into the aquatic environment in the Jordan Creek drainage system. The DeLamar mill waste products have been documented as the major source of the mercury contamination. Fishermen have been warned of the possibility of mercury poisoning by regular consumption of fish caught in the Jordan Creek drainage system. Southeastern Idaho is the site of much active phosphate mining. Associated with these active mines are some inactive sites which are identified with water quality degradation. Two of these areas are Georgetown (ID-8) and Waterloo (ID-9).

Some sediment problems associated with dredge mining have been identified at Beaver Valley (ID-4) and Mores Creek (ID-10). However, these problems are not well defined and do not appear to pose any major water quality problems.

Various Federal and state agencies are conducting on-going studies of the inactive mine drainage problem in Idaho. One study to be conducted by the U.S. Forest Service will examine extreme northern Idaho including the Jack Waite (ID-11) and Continental (ID-12) Mines. The Idaho State Department of Health will examine the mercury problem in the Silver City area, and possibly other problem areas in the state as well. However, results of this work are not expected until mid 1976 or later. When completed, the studies should provide clarification of the problem areas identified herein.

ILLINOIS

AGENCIES CONTACTED

- State Environmental Protection Agency, Water Pollution Control Division
- U.S. Environmental Protection Agency
- U.S. Geological Survey

Summary of Findings

No water quality problems were reported within the scope of this study.

INDIANA

AGENCIES CONTACTED

- State Forestry Department
- State Stream Pollution Control Board, Industrial Waste Section
- U.S. Environmental Protection Agency
- U.S. Geological Survey

Summary of Findings

One water quality problem associated with inactive mining was reported. Solid waste disposal in an abandoned limestone quarry has caused groundwater pollution. However, this is a result of improper solid waste disposal and not associated with mining activities.

IOWA

AGENCIES CONTACTED

- State Department of Environmental Quality, Water Quality Management Division
- State Geological Survey
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service

Summary of Findings

No water quality problems were reported within the scope of this study.

KANSAS

AGENCIES CONTACTED

- State Department of Health and Environment, Division of Environment Water Quality Programs
- U.S. Environmental Protection Agency
- U.S. Geological Survey, Water Resources Division
- U.S. Fish and Wildlife Service

Summary of Findings

The Tri-State lead and zinc mining area (see Missouri) extends into the southeastern portion of the state. Water quality problems in the Tri-State area in Missouri led to suspicion of similar problems in the Kansas region. No complaints were received and there was no documentation of water quality problems.

KENTUCKY

AGENCIES CONTACTED

- State Department of Natural and Economic Resources, Division of Environmental Management
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service

Summary of Findings

No water quality problems were reported within the scope of this study.

LOUISIANA

AGENCIES CONTACTED

- State Stream Control Commission
- State Wildlife and Fisheries Department
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service
- U.S. Geological Survey, Water Resources Division

Summary of Findings

No water quality problems were reported within the scope of this study.

MAINE

AGENCIES CONTACTED

- State Department of Environmental Protection
- Bureau of Water Quality Control

- State Geological Department
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service
- U.S. Geological Survey

Summary of Findings

There are few inactive mines in the state, however, no significant water pollution problems were reported from these mines.

Initial contacts with some agencies indicated that the Callahan Mine (a copper and zinc mine) near Castine, Maine was a source of pollution to the nearby marine estuaries. However, the mine is currently active. Abandoned limestone quarries at Camden and Rockland are being used as dump and have caused some concern regarding groundwater contamination but no further documentation was reported to substantiate this concern.

The state of Maine, Department of Sea and Shore Fisheries, is currently undertaking a research project sponsored by the Environmental Protection Agency to determine levels of metals and shellfish in marine areas adjacent to active and inactive copper and zinc mines.

MARYLAND

AGENCIES CONTACTED

- State Department of Natural Resources
- State Environmental Health Administration
- U.S. Bureau of Land Management
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service

Summary of Findings

An abandoned quarry was suspected of having an acid drainage. No documentation was found regarding the magnitude or location of the problem.

MASSACHUSETTS

AGENCIES CONTACTED

- State Department of Natural Resources, Division of Water Pollution Control
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service
- U.S. Geological Survey
- National Park Service

Summary of Findings

No water quality problems were reported within the scope of this study.

MICHIGAN

AGENCIES CONTACTED

- ° State Bureau of Water Management
- ° Department of Natural Resources, Fisheries Division
- ° U.S. Environmental Protection Agency
- ° U.S. Forestry Service
- ° U.S. Geological Survey
- ° National Park Service

Summary of Findings

Low pH water and sewage effluent have affected 10 to 13 kilometres of the Iron River. There is no consensus regarding the source of the low pH water. The drainages are from a basin that has had previous iron mining activity, however, there is disagreement as to whether the acid drainage is caused by inactive mines or naturally caused. It was speculated by some agencies contacted that acid drainage may have been caused by groundwater rising to a sufficient elevation to contact sulfur bearing rock.

MINNESOTA

AGENCIES CONTACTED

- ° State Geological Survey
- ° State Water Pollution Control Agency
- ° U.S. Environmental Protection Agency

Summary of Findings

Water resources investigation and a water quality network throughout the state have revealed no problems related to past mining activities.

MISSISSIPPI

AGENCIES CONTACTED

- ° State Air and Water Pollution Control Commission, Division of Water Pollution Control
- ° State Game and Fish Commission
- ° U.S. Environmental Protection Agency
- ° U.S. Fish and Wildlife Service
- ° U.S. Geological Survey

Summary of Findings

Past problems of increased turbidity from bentonite mining in the northern part of the state have been investigated and solved by local authorities.

MISSOURI

AGENCIES CONTACTED

- ° State Department of Natural Resources, Division of Environmental Quality, Water Quality Programs
- ° Ozark Gateway Regional Commission
- ° U.S. Department of the Interior, Bureau of Mines
- ° U.S. Environmental Protection Agency
- ° U.S. Fish and Wildlife Service
- ° U.S. Geological Survey

Summary of Findings

Drainage from four mining areas within the state are affecting water quality in approximately 135 kilometres of stream and rivers. Two problem areas are within the old lead belt (Mine - La Motte and Flat River-Bonne Terre MO-1 & 2) where high metal concentrations are the source of water quality degradation. Acid does not appear to be a problem. Measurement at MO-1 shows a high pH (8.0) and no measurements were reported at MO-2.

In the Flat River - Bonne Terre District (MO-2) sediments that either washed down during active operations or continue to erode from tailings are the source of high metal concentrations in Flat River and the Big River. Although the water quality is marginal in the river, benthic fauna are greatly depressed and there is little or no fish production. This is illustrated by a comparison as shown in Table D.1 of concentration of metals in the water and the stream sediments.

TABLE D.1. CONCENTRATION OF METALS IN WATER AND SEDIMENT

Metal	Concentration (mg/l)	
	Water	Sediment
Al	0	19,000
Cu	10	340
Fe	130	188,000
Mn	80	27,000
Pb	130	19,000
Zn	70	11,000

There are approximately 20-30 inactive barite mines in the Washington County Tiff Mining District (MO-3). Abandoned tailings ponds continually erode causing sedimentation in three rivers (Mill Creek, Old Mine Creek, and Mineral Ford Creek). Occasionally one of these ponds breaks, causing severe problems. In August, 1975 a dam failure resulted in 64 kilometres of stream pollution (discoloration, turbidity, etc.).

The Tri-State area (MO-4) has been extensively mined for lead and zinc. There are between 30 and 100 inactive mines. Seepage from the mines has caused the concentration of zinc in Center Creek and Turkey Creek to be in excess of the toxic limits for adults of some fish species and eggs and fingerlings of most species. Nevertheless, water from some of the mines is of sufficiently high quality for municipal use.

MONTANA

AGENCIES CONTACTED

- State Department of Health and Environmental Science
- State Department of Natural Resources, Water Resources Division
- State Department of Lands
- State Fish and Game Department
- State Bureau of Mines and Geology
- Anaconda Company
- U.S. Forestry Service
- U.S. Bureau of Land Management

Summary of Findings

Drainage from fourteen large inactive mining areas affected the water quality of about 160 kilometres of streams. Most of the water quality problems are caused by acid mine drainage and high concentrations of heavy metal; however, sediment problems are created by some mining activities.

Several mines (MT-1) in the vicinity of Hughesville (70 kilometres southeast of Great Falls) contribute significant amounts of iron, manganese, and zinc to the waters of Galena Creek. Approximately 3 kilometres of Galena Creek are affected. The major source of pollutants in the area is seepage from the Block P Mine tailings dump which discharges highly acidic water to Galena Creek. The State of Montana has taken flow measurements and chemical analysis of drainage flows since July 1973 in order to formulate a plan for preventing further pollution of Galena Creek [Montana 1974b].

The McClaren Mill (MT-2) is located near Cooke City. The mill tailings cover about 4.5 hectares and contain approximately 117,045 cubic metres of tailings. The tailings discharge highly acidic water into Soda Butte Creek. The water enters tailings from three sources: creek, snowmelt, and precipitation. The Bear Creek Mining Company has considerably lowered the level of pollution by relocating Soda Butte Creek in the tailings area and by regrading the tailings. Approximately three kilometres of Soda Butte Creek are still devoid of aquatic life due to the acid drainage [Montana 1975].

The McClaren Mine mine (MT-3) area covers about 8 hectares. Dumps, waste piles, and disturbed areas contain approximately 82,600 cubic meters of material. Precipitation, snowmelt, and groundwater percolate through the wastes to leach metal ions and acids from the materials.

Additional acid drainage originates from open-pits and adits. About 6 kilometres of stream are affected by the drainage. Streams involved are Daisy Creek and the Stillwater River [Montana 1975].

The Glengary Mine (MT-4) is located about 6 kilometres north of Cooke City. The area covers about 3 hectares. The ground suface has been disturbed by road and trench construction and by formation of several small mine dumps. Surface flows and snowmelt leach metals from the disturbed areas into Fisher Creek. In addition, highly acidic water drains from the adit into the creek. Apparently groundwater is the major source of flow from the adit. Approximately 5 kilometres of Fisher Creek are affected by the acid drainage [Montana 1975].

The Comet Mine (MT-5) is located on High Ore Creek about eleven kilometres northwest of Boulder. Base metal ions are leached from the tailings and enter High Ore Creek. Approximately 6 kilometres of High Ore Creek are sterile because of the acid drainage. The Boulder River has been degraded several kilometres downstream of its confluence with High Ore Creek. Considerable erosion of the tailings occurs when High Ore Creek freezes and water overflows onto the tailings [Montana 1974a].

The Crystal Mine (MT-6) is located about 48 kilometres northeast of Butte near Cataract Creek, a tributary to the Boulder River. Acid drainage from several adits is the primary problem. The drainage water contains high concentrations of heavy metals, primarily zinc, iron, copper, and manganese. About 10 kilometres of Cataract Creek below the mines are devoid of fish life. The Boulder River is severely degraded for 16 kilometres downstream of Cataract Creek.

The Elkhorn Mining District (MT-7) is located about 64 kilometres southwest of Butte. The major problem caused by the district is drainage from two adits, the Upper Elkhorn and the Lower Elkhorn Mines. Additional heavy metals are added to the lower mines drainage as it flows through a tailings pile. Drainage from the district has caused Elkhorn Creek to become sterile for about 5 kilometres. Analyses of water drainage from the mines indicates that heavy metal concentrations are low in comparison to the sulfate concentrations. Because acidity is lower than expected, the drainage water is probably partly neutralized by natural limestone. While metal concentrations are fairly low, the relatively high flow rate of water from the mines causes a large enough pollutant loading to damage the stream.

The Heddleston District (MT-8) is a lead and zinc mining area located about 56 kilometres northwest of Helena. Drainage from the district's adits and tailings have degraded the Upper Blackfoot River for about 13 kilometres below the mines. Heavy rainfall in 1975 caused large runoff flows which breached the tailings pond dam and washed tailings into the upper Blackfoot River.

Grasshopper Creek (MT-9) contains several placer mining sites near Bannack, about 96 kilometres southwest of Butte. The primary problem created by the mining activities is a heavy sediment load in Grasshopper

Creek from Bannack to its confluence with the Beaverhead River. Hydraulic mining was practiced extensively in the area to produce gold from the terrace deposits along the creek. Large waste piles accumulated along the creek bed. Occasionally these are undercut by the stream, allowing large amounts of tailings to fall into the stream. Approximately 24 kilometres of Grasshopper Creek have been affected by the resulting sediment loads.

The Sunshine Lead Prospect (MT-10) is a small exploratory site that produced small amounts of ore for several years. The prospect is located near Hyalite Creek about 16 kilometres south of Bozeman. The mine itself does not cause a water quality problem, but a natural spring near the mine discharges water with significant concentrations of base metals. At the present time the discharge does not enter Hyalite Creek, but infiltrates into the hillside. The spring does present a potential problem, however, because Hyalite Creek is the primary water supply for the City of Bozeman the discharge is a concern.

The Alta Mine area (MT-11) is a large complex of open pit and underground mines, and milling operations. The area is located near Corbin Creek about 56 kilometres northeast of Butte. Acid drainage from the workings contributes substantial amounts of iron, manganese, and zinc to the waters of Corbin Creek and Prickly Pear Creek. About 9 kilometres of streams are severely affected.

The Frohner mine area (MT-12) is located about 24 kilometres southwest of Helena. The area consists of underground mines and tailings. Acid mine drainage enters Lump Gulch, a tributary to Prickly Pear Creek, and degrades about 5 kilometres of stream. The problem is especially significant because Park Lake, a popular recreation area, is fed by Lump Gulch. The drainage water contains high concentrations of arsenic.

The Gold Creek Placer area (MT-13) is a series of placer mining sites along the north and south forks of Gold Creek, about 64 kilometres northwest of Butte. Over the last 60 years, hydraulic mining extensively damaged the streambed and banks. As a part of the operation, the North Fork was diverted into the South Fork. The stream relocation caused severe erosion during periods of high stream flow and about 32 kilometres of Gold Creek have been adversely affected by sediment loadings.

The Forest Rose Mine (MT-14) is located near Dunkleberg Creek, a tributary to the Clark Fork River, about 8 kilometres north of the Gold Creek Placers. Mineralized water flows from the mine adit and through the tailings before reaching the creek however, no estimate is available on the length of creek adversly affected.

Anaconda operates a large copper mining complex about 32 kilometres northwest of Butte (MT-15). The operation includes open pit and underground mines, ore concentraters and tailings. Both active and inactive mines exist in the area. The magnitude of the pollution problem from the inactive mines is difficult to assess because mine drainage and mill wastewater from several operations are treated in one central area before being discharged to the Clarks Fork. Considerable degradation of the Clarks Fork occurred before treatment facilities began operating. About 26 kilometres of Clarks Fork are affected.

At the present time, mine drainage and processing wastewater are treated in the tailings pond by addition of lime. Most of the metals are precipitated in the tailings pond as hydroxides. Pond effluent is considerably higher quality than influent.

Proposals for Pollution Abatement

Pollution abatement efforts at several abandoned mine sites have been studied by various governmental agencies. Abatement efforts at some of the problem areas are discussed further.

The most feasible means of abatement in Galena Creek involves segregating the creek from the seepage because the major pollutant load from the area enters the creek at a discrete spot. A study by the Department of Natural Resources and Conservation determined that the best method would be to route the creek through a pipeline in the area of the seepage [Montana 1974b]. The seepage from the tailings can then be treated separately.

The McClaren Mill, McClaren Mine, and Glengary Mine are all located in a small area near Cooke City. Pollution abatement of these sites is being studied by the Department of Natural Resources and Conservation [Montana 1975]. Hydrologic studies are being conducted to determine the most practical method of treatment.

It is possible that the problems due to seepage from the tailings may be solved by the use of excess cut material from the future construction of Interstate 15 between Boulder and Butte. Highway construction is expected to create large quantities of excavated material that will have to be disposed of. The Fish and Game Department and Department of Health are studying the possibility of using the excavated material to dam High Ore Creek and submerge the tailings. It is expected that once the tailings are covered with water and deposited organic matter, the oxidation of pyrites in the tailings will be halted.

It is expected that the underground operations at Crystal will be reactivated. In this case, the drainage will fall under existing state mining and water pollution controls, and the mine owners will be responsible for abatement of pollution.

NEBRASKA

AGENCIES CONTACTED

- ° State Department of Environmental Control, Water Pollution Control
- ° U.S. Environmental Protection Agency
- ° U.S. Fish and Wildlife Service

- U.S. Geological Survey
- National Park Service

Summary of Findings

No water quality problems were reported within the scope of this study.

NEVADA

AGENCIES CONTACTED

- State Department of Human Resources, Environmental Protection Services
- State Bureau of Mines and Geology
- U.S. Bureau of Mines

Summary of Findings

In spite of Nevada's extensive mining history, only two inactive mines were found to be causing water pollution problems. It was expected that the Sutro Tunnel, a drainage tunnel under the Virginia City mines, might be a source of pollution. Drainage from the Sutro Tunnel, however, is contained in ponds built on the tailings from the mine. Overflow from the ponds is apparently caught by irrigation ditches.

The Jarbidge Mine (NV-1) is located in Jarbidge, about 118 kilometres north of Elko. It is an underground gold and silver mine which was abandoned in the 1930's. The major problem caused by the mine's drainage is aesthetics. The mine discharges a small flow of colored water which is slightly acidic but apparently not enough to dissolve heavy metals.

The Rio Tinto Mine (NV-2) is located about 42 kilomtres west of the Jarbidge Mine. Seepage from the tailings enters Mill Creek, a tributary to the Owyhee River. The discharge varies considerably in chemical quality but generally is very acidic and contains large amounts of iron and copper. The most recent operation at the mine was an acid leach.

Seepage from the tailings has caused several fish kills in the Owyhee River during the last 20 years. The mine owners successfully isolated the main seepage from the tailings so that it could be diverted back to the mine for treatment. However, previously unknown seeps in the tailings continued to cause problems. The leaching operation was abandoned in early 1975.

NEW HAMPSHIRE

AGENCIES CONTACTED

- State Water Supply and Pollution Control Commission
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service
- National Park Service

Summary of Findings

Although some local water pollution problems can be attributed to mining activities, it was reported that in many cases high sediment and salinity loads are not attributable to the activities of man. Except for some special situations, pollutants in surface water are attributed to natural conditions, and urban discharges. Radioactive contamination of both surface and groundwater in the Grants Mineral Belt area of northwestern New Mexico has been documented recently, although it has not been proven whether the radioactivity exists naturally or is man-caused. The Animas and San Juan Rivers have elevated levels of uranium and radium. These levels are considered to be the result of leachates derived from tailings developed at uranium mining operations. Amounts of radium, selenium, and vanadium sufficient to render surface water in the Rio Paguate, Arroyo Del Puerto, and Rio Puerco drainages unfit for domestic livestock and irrigation use have been reported. Radioactive contamination of groundwater has been detected in close proximity to the centers of uranium production, along with widespread selenium concentrations in areas adjacent to separate milling facilities. The natural occurrence of selenium in water is common in arid and semiarid climates.

NEW YORK

AGENCIES CONTACTED

- State Department of Environmental Conservation, Division of Pure Waters
- State Department of Environmental Conservation, Bureau of Industrial Programs
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service
- U.S. Geological Survey
- National Park Service

Summary of Findings

Two iron mines are noteworthy although they apparently do not cause serious water quality degradation. An NPDES permit has been applied for at the Adirondack iron mine (NY-1) and no water quality degradation has been reported in the receiving stream. The effects of the discharge at the Stella Mine (NY-2) are under study and not known at this time.

The owner of the Stella Mine has attempted to minimize the effects of the discharge by ditching around the tailings and covering the pile with limestone. Apparently this has had limited effect on the quality of the discharge.

NORTH CAROLINA

AGENCIES CONTACTED

- State Department of Natural and Economic Resources, Division of Environmental Management
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service

Summary of Findings

Mining and retroactive environmental regulations now being enforced have resulted in the resolution of all significant water pollution problems in the state. Siltation of 65 to 80 kilometres of the Nolichucky River in Tennessee has been attributed to the Spruce Pine Pegmatite (feldspar, mica, and quartz) Mining District (NC-1). The mines are located in the upper reaches of the drainage basin where the stream gradient is steeper than in the lower portion of the basin. The steeper stream gradient has a greater capacity to transport sediment; as a result the sediment settles out when the grade flattens.

There are approximately ten active and fifty inactive mines. Most of the inactive mines were small one or two man operations. The bulk of the problems apparently stem from a few major active mines.

NORTH DAKOTA

AGENCIES CONTACTED

- U.S. Environmental Protection Agency
- U.S. Geological Survey

Summary of Findings

No water quality problems were reported within the scope of this study.

OHIO

AGENCIES CONTACTED

- State Environmental Protection Agency, Water Pollution Control Division
- State Department of Natural Resources
- U.S. Environmental Protection Agency

Summary of Findings

A clay mine in the vicinity of some coal mines was suspected of an acid discharge by one source. The location and magnitude of the problem was unknown. No documentation was found to substantiate this data.

OKLAHOMA

AGENCIES CONTACTED

- State Department of Mines
- State Department of Pollution Control
- State Geological Survey
- State Water Resources Board, Water Quality Division
- U.S. Environmental Protection Agency

Summary of Findings

Local problems exist in Oklahoma within the McAllister, Bartlesville, and Henrietta areas. Acid mine waters containing iron and manganese are creating some minor surface water contamination in the McAllister area. Some heavy metal concentrations have been reported in surface waters draining the Bartlesville area; these problems are a result of the erosion and runoff from smelter slag piles. Similar conditions exist from inactive strip mining and custom smelter operations in the zinc mining area near Henrietta, Oklahoma. Both sedimentation and heavy metal concentrations are problems.

OREGON

AGENCIES CONTACTED

- State Department of Environmental Quality, Water Pollution Control Division
- State Department of Geology and Minerals
- U.S. Environmental Protection Agency
- U.S. Geological Survey
- National Park Service

Summary of Findings

Five inactive mines are known to be the source of varying water quality problems. Many of the mines are located near large streams which dilute the discharge. Therefore, only an estimated 37 kilometres of stream system are affected. Specific problems are discussed below.

White King Mine (OR-1) is located in southern Oregon about 100 kilometres east of Klamath Falls. The mine has caused sediment problems in Auger Creek. Drainage from the mine enters a small lake which normally has no surface outlet, but spring flows usually cause the lake to overflow to Auger Creek. About 16 kilometres of Auger Creek were reported to have been sterilized when the mine was pumped out.

The Blackjack Mine (OR-2) is located on Clear Creek about 100 kilometres southeast of Pendleton. Highly acidic water entering Clear Creek is the major problem caused by the mine. Heavy metal concentrations are relatively small with the exception of iron.

The Couger-Independence (OR-3) Mine is located about 10 kilometres northeast of the Blackjack Mine. Acid drainage from the mine containing significant quantities of iron and manganese enters Granite Creek.

The Silver Peak Mine (OR-4) is located about 47 kilometres north of Grants Pass. Acidic water discharges into a small stream which is tributary to Canyon Creek. The drainage also contains significant quantities of iron, zinc, and manganese.

The Alameda mine (OR-5) is a large underground mine located on the Rogue River about 30 kilometres northwest of Grants Pass. Gold and Copper were mined from a large sulfide zone which also contained lead, zinc, and silver. The mine was abandoned in the 1930's. The major problem caused by the mine is acid mine drainage. Plant life is very scarce near the stream and an aesthetic problem is also caused by the colored drainage water.

PENNSYLVANIA

AGENCIES CONTACTED

- State Department of Environmental Resources, Bureau of Water Quality Management
- State Division of Mine Drainage Control and Reclamation
- U.S. Bureau of Mines
- U.S. Environmental Protection Agency
- U.S. Geological Survey
- U.S. Fish and Wildlife Service

Summary of Findings

Some of the people contacted suspect past clay and mining activities of causing minor acid drainage. No documentation regarding the location or magnitude for the problem was found. No other water quality problems from mine drainage within the scope of this study were reported.

RHODE ISLAND

AGENCIES CONTACTED

- State Water Pollution Control, Division of Water Supply and Pollution Control
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service
- U.S. Geological Survey
- National Park Service

Summary of Findings

No water quality problems were reported within the scope of this study.

SOUTH CAROLINA

AGENCIES CONTACTED

- ° State Department of Health and Environmental Control
- ° State Land Resources Conservation Commission
- ° State Development Board, Division of Geology
- ° U.S. Environmental Protection Agency
- ° U.S. Fish and Wildlife Service

Summary of Findings

A potential problem from lithium bearing tailings originating in North Carolina is suspected. However, no documentation was available.

SOUTH DAKOTA

AGENCIES CONTACTED

- ° State Department of Environmental Protection
- ° U.S. Environmental Protection Agency
- ° U.S. Geological Survey

Summary of Findings

Minor problems of tailings erosion were cited. In addition, small intermittent acid discharges were noted for fish kills. The scope and magnitude of these problems was not documented. No other information was available.

TENNESSEE

AGENCIES CONTACTED

- ° U.S. Environmental Protection Agency
- ° U.S. Forestry Service
- ° U.S. Fish and Wildlife Service

Summary of Findings

Four problems are in part attributable to past mining activities. The Nolichucky River has been degraded by mining activities, however, the source is in North Carolina (NC-1).

The Ball Clay District (TN-1), a surface mining area approximately 95 percent active, is the source of intermittent sedimentation from erosion of disturbed land and waste piles. The Brown Phosphate District (TN-2), a surface mining area approximately 95 percent active, has caused fish kills from discharge of slimes.

In the Ducktown District (TN-3), a copper and iron sulfide mining area, large areas of land were denuded from sulphurous fumes from old ore roasting operations. This has resulted in excessive soil erosion, acid discharges, and siltation in 30-40 kilometres of the north Potato Creek and the Ocoee River. Approximatly 90 percent of the mining in this region is still active.

In the East Tennessee Zinc District (TN-4) there are four active and one inactive zinc mining operations which cause sedimentation and heavy metals concentration in Mill Creek.

Strip mining of manganese in the eastern part of the state has been the source of some undocumented complaints of sedimentation. Further investigation will verify the validity of these complaints.

TEXAS

AGENCIES CONTACTED

- State Water Quality Control Board, Industrial Services Section
- State Wildlife Department
- U.S. Environmental Protection Agency
- National Park Service

Summary of Findings

In the Uranium District (TX-1) of southeast Texas approximately 30 mines, of which approximately 20 are inactive, have a potential of radioactive pollution from tailings erosion. No documentation regarding this problem was discovered.

In the Terlingua District (TX-2), an inactive mercury mining area in the Big Bend National Forest, mercury concentrations in the sediments of Terlingua Creek have been measured as high as 0.3 ppm. Little or no mercury was found in the waters draining the area. Opinions differ on the source of the mercury. Undoubtedly some of the mercury can be attributed to naturally occurring deposits which wash into the creek. However, no consensus exists regarding the extent of the contribution from tailings.

UTAH

AGENCIES CONTACTED

- State Bureau of Environmental Health
- U.S. Environmental Protection Agency
- U.S. Forestry Service
- U.S. Geological Survey

Summary of Findings

No water quality problems were reported within the scope of this study.

VERMONT

AGENCIES CONTACTED

- ° State Agency of Environmental Conservation
- ° State Geological Survey
- ° U.S. Environmental Protection Agency
- ° U.S. Fish and Wildlife Service
- ° U.S. Geological Survey
- ° National Park Service

Summary of Findings

Drainage from three inactive copper mines (VT-1,2 and 3) is causing water quality degradation to approximately 14 kilometres of streams. Activity at these mines dates back as far as 1793. The ore consists of chalcopyrite disseminated in pyrrhotite, with the latter being one of the most readily oxidized acid forming iron sulfides. According to native history, the copper deposits in this region were discovered through observation of the colored water in the creeks. Undoubtedly the mining activities have accelerated the rate of pollution and increased its magnitude.

Data available on VT-1 and VT-2 were insufficient to calculate any loading rates. The most significant problem has been reported at VT-3. Therefore, the loading from the other mines is assumed to be less.

The major source of acid has been reported to be tailings. This may be explained as follows: 1) At VT-2 the mining operations were conducted to a vertical depth of 1,500 below the surface and are not free-draining; 2) At VT-3 the adits drain into the tailings pile and seep through it.

VIRGINIA

AGENCIES CONTACTED

- ° State Water Control Board
- ° U.S. Environmental Protection Agency
- ° U.S. Fish and Wildlife Service
- ° U.S. Geological Survey

Summary of Findings

The State of Virginia has only a few water quality problems due to inactive mine drainage. Three separate locations have been identified.

Acid mine drainage is a problem noted at two locations: Contrary Creek (VA-1); and Chestnut Creek (VA-2). Both locations have old pyrite mines with the Contrary Creek site composed of three separate operations. Approximately 8 kilometres of Chestnut Creek are reported to be sterile, as well as 15 kilometres of Contrary Creek, due to the acid drainage. Implementation of an abatement project at the Contrary Creek site is scheduled to begin in April 1976. The work involves reclamation of two of the three operation sites, Boyd Smith, and Sulphur mines. This includes reconstruction and revegetation of stream channels and removal of contaminated material from the streambed. No reclamation of the downstream channel is included. Project completion is scheduled for late summer 1976 with water quality monitoring to continue through 1978. The third location, Kelly Bank (VA-3), is reported to be causing sediment problems due to failure of sediment trap dam.

WASHINGTON

AGENCIES CONTACTED

- Department of Ecology, Water Quality Management
- U.S. Bureau of Mines
- U.S. Environmental Protection Agency
- National Park Service

Summary of Findings

One inactive mine is reported to cause water quality problems. The Holden Mine (WA-1) is a large operation located on Railroad Creek about 140 kilometres northeast of Seattle. It produced copper, zinc, silver and gold from 1937 to 1957.

Large amounts of sediment eroded from the tailings, by wind and water, have been deposited in Railroad Creek. Seepage from the tailings drains into the creek and contributes acidity and high concentrations of copper, iron, and zinc to the creek.

Railroad Creek is a glacial stream and is naturally low in nutrients. Because of this relatively little flora or fauna exists in Railroad Creek, even upstream of the mine. Discharge from the mine has nearly removed what little life did exist. Approximately 14 kilometres of stream are degraded by the mine discharge to its outlet into Lake Chelan [Pine 1967].

WEST VIRGINIA

AGENCIES CONTACTED

- State Department of Natural Resources
- State Water Control Board
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service

Summary of Findings

No water quality problems were reported within the scope of this study.

WISCONSIN

AGENCIES CONTACTED

- ° State Department of Natural Resources, Fisheries Division
- ° U.S. Environmental Protection Agency
- ° U.S. Geological Survey

Summary of Findings

The zinc mining district (WI-1) in the southwestern portion of the state was the only problem area reported. Approximately 10 kilometres of stream have been affected by acid water and sedimentation from the tailings of the old zinc workings. Although the area is now inactive, it is expected to be reactivated in the near future.

WYOMING

AGENCIES CONTACTED

- ° State Department of Fish and Game
- ° State Water Quality Division

Summary of Findings

The only mine pollution problem indicated, was the Ferris-Haggerty Mine in Carbon County. The mine, which was abandoned in 1905, has adversely affected 8 kilometres of stream. The mine has recently been reactivated and the state will impose discharge requirements on the owner.

WATER POLLUTION FROM URANIUM MINES AND MILLS

The uranium industry is dissimilar to base metal mining where the mine and mill are frequently located in close proximity to each other. Uranium mines on the Colorado Plateau are usually quite small and located in remote areas widely separated from each other. Usually the mines are short lived. The ore is trucked to a central mill where all processing takes place. Most pollution problems are associated with the mill, not the mine. It is possible that a few of the mines may have water running from the tunnels but such water is not acid though it may be radioactive. Most carnotite mines are small, dry holes in the permeable sandstone. Such sandstones are seldom aquifers, since they are located on canyon rims. Thus most pollution problems in the uranium industry are a result of milling activities. Water pollution problems exist because most mills are located on rivers; elsewhere on the Colorado Plateau water is scarce.

Pollution from uranium mills involves radioactive pollution, a special hazards about which the general populace knows little. It can take many forms:

1. Alpha, beta, and gamma emmissions.
2. Ingestion of radioactive particles into the lungs.
3. A generally higher than normal ambient radioactivity level.
4. Breathing of radioactive radon gas which can result in lodging radioactive disintegration products in the lungs.
5. Drinking radioactive water which can result in lodging radioactive sites in the digestive tract.

Aside from airborne dust and radioactive particles, most of these radiation products are water-borne and can result in significant stream and aquifer pollution.

In the early days of carnotite extraction on the Colorado Plateau, small plants existed for the recovery of radium from the ore. This same ore was processed later for its vanadium content, and for its uranium content. It is currently processed for its combined uranium-vanadium content.

The first radium facility was operated in the 1920's at Uravan, Colorado. There the carnotite-bearing Salt Wash member of the Morrison formation outcropped in the gorge of the San Miguel River in western Colorado. This provided ore, water, coal, and flat land at one location. Subsequent vanadium plants using the salt roast process operated in many locations in the Colorado Plateau region.

Until about 1950, these early plants discharged their tailings to the nearby rivers, thus ridding themselves of salts, ground sandstone, and all the radioactive daughter products. These salts, sands, and radioactive daughters became part of the river's mud and sand bars. Some of the earliest tailings may even have penetrated to the Gulf of California. After Boulder Dam was built, many of the radioactive tailings were deposited into Lake Mead. Lake Powell would now catch whatever escapes the mills, but tailings are no longer dumped into rivers. Presently, salts are evaporated in impermeable ponds.

Other aspects of pollution from uranium processing facilities have recently come to light. Reports exist that drinking water in the Grants and Ambrosia Lake areas in New Mexico contains "intolerable" levels of radioactive and poisonous wastes such as selenium [Roase 1976, USPHS 1957]. It is also known that at least one of the uranium mills in the area has been injecting liquid waste materials in a deep aquifer by means of an injection well [Lynn 1967]. Whether such solutions remain 'buried' in the desired aquifer appears questionable. At any rate, Radon 222 contamination of drinking water in the Grants area is a serious problem.

A similar situation exists in regard to the site of the former Vitro Uranium Company uranium mill in south Salt Lake City, Utah [Duncan 1974]. This site has been abandoned since 1964 for uranium use and since 1960 for any industrial use. The tailings are unconsolidated and are frequently airborne. Groundwater contamination has occurred in the shallow aquifers under the tailings and gamma-ray measurements on the tailings are substantial. Radon and radon-progeny readings in several buildings on the site are high. There is evidence that some of the tailings have been removed for construction material in the Salt Lake Valley and radiation from these sources is often an unsuspected hazard.

In Grand Junction, Colorado, the tailings from the Climax Uranium Company operation were widely used for construction and fill in the Grand Junction area before it was realized what was happening. There was a tremendous local interest in the problem and many articles were published in the Grand Junction Sentinel over a period of six years on the subject. [Daily Sentinel]. In 1975, many of the fills made from tailings were removed through an extensive correction program.

In south Texas there is concern over aquifer pollution from in-situ uranium recovery plants which are currently active. In-situ recovery methods have unique pollution problems and special techniques are necessary for effective control.

The Shiprock mill located in the northwest corner of New Mexico has been shut down since 1968 [U.S. Atomic Energy Commission 1974a]. A recent survey (1974) of the site showed many possible pollution conditions existed. The southern tailings areas have been used for a training ground for large equipment operators and the tailings are consequently loose and frequently windblown. There is general radioactive contamination by deposited and wind-borne sand. The areas of contamination are 1,000 feet beyond the plant fence borders.

The uranium mill tailings are situated on a bluff overlooking the southwest bank of the San Juan River. Storm runoff empties into the river, after passing through the contaminated area. Radioactive pollution of the San Juan has certainly occurred in the past and can be expected to occur in the future until the tailings are covered, stabilized, and anchored down by suitable vegetation.

Water supply for the town of Shiprock is diverted from the San Juan. It is possible that the high winds of the Shiprock area have carried radioactive particles into the San Juan above the water supply intake. Data on pollution possibilities at twenty other inactive mill sites have also been published by the AEC [USAEC 1974a].

Recent newspaper publicity discusses use of uranium tailings at Port Hope, Ontario, Canada for building purposes in the area, with results similar to the Grand Junction, Colorado experience [Arizona Daily Star 1976]. It may be necessary to remove all tailings used for such purposes and re-bury them elsewhere in order to reduce radiation levels in homes to natural levels.

Revegetation of tailings is a valid and useful technique in reclamation of most mining dump areas, but in uranium the method is dangerous [EPA 1973k]. The irrigation necessary to establish vegetation in arid areas may result in radioactive pollution of groundwater. Riprap might be a better solution for stabilization of blowing uranium mill tailings in arid, windy areas.

TABLE D-2. ARIZONA

Mine or District	Map Reference	Water Quality Impact		Problem Type	Associated With	Type Mining	Materials Mined	Mine Discharge (l/sec)	pH	Annual Loading (metric tons/yr)					
		km of Stream	Beneficial Use							Acid As $CaCO_3$	Fe	Cu	Mn	Zn	SO_4
Sheldon	AZ-1	[a]	Fish	Acid Metals	Tailings	Underground	Au,Ag,Cu	0.19	3.0	18	8[b]	<0.1	(1)	<0.1	11
Patagonia	AZ-2	-	Aesthetics	Sediment	Tailings	Underground	Pb,Ag,Cu			NO DATA AVAILABLE					
Globe-Miami	AZ-3	[b]	Domestic	TDS	Tailings Processing	--	Cu			NO DATA AVAILABLE					

[a] Fish production in small (20 Hectare) lake limited.

[b] Groundwater affected.

TABLE D-3. ARKANSAS

Mine or District	Map Reference	Water Quality Impact		Problem Type	Associated With	Type Mining	Materials Mined	Mine Discharge (l/sec)	pH	Annual Loading (metric tons/yr)					
		km of Stream	Beneficial Use							Acid As $CaCO_3$	Fe	Cu	Mn	Zn	SO_4
Rush-Maumee Ponce-Boxley	AK-1	[a]	[b]	Sediment	Tailings	Surface Underground	Pb,Zn			NO DATA AVAILABLE					
Magnet Cove	AK-2	[a]	[b]	Sediment	Tailings Pits	Surface Underground	Barite			NO DATA AVAILABLE					
Bauxite	AK-3	[a]	-	Acid	-	-	Bauxite			NO DATA AVAILABLE					

[a] No estimate made of length of stream effects.

[b] Possibly stressed benthic community.

TABLE D-4. CALIFORNIA

Mine or District	Map Reference	Water Quality Impact		Problem Type	Associated With	Type Mining	Materials Mined	Mine Discharge (l/sec)	pH	Annual Loading (metric tons/yr)					
		km of Stream	Beneficial Use							Acid As $CaCO_3$	Fe	Cu	Mn	Zn	SO_4
Gray Eagle	CA-1	3[a]	Fish	Acid	Adit, Tailings	Underground	Cu	5.0	2.9	213	20	9	(8)	4	(204)
Almadin	CA-2	2[b]	Fish	Hg	Adit Tailings	Underground [c]	Hg	NA	NA	NA	NA	NA	NA	NA	NA
Buena Vista	CA-3	2[d]	Fish	Acid Heavy Metals	Adit, Tailings Pits	Underground Surface	Hg	.25	3.6	56	5	(1.0)	(2.0)	(2)	(53)
Leviathan	CA-4	15	Fish Stock Watering	Acid Heavy Metals	Adit, Tailings Pits	Underground Surface	Sulphur	8.3	1.6	6100	560	8	1	(90)	390
Walker	CA-5	24	Fish	Acid	Adit, Tailings	Underground	Cu	14.2	4.5	370	(34)	7	(13)	0.3	(350)
Penn	CA-6	3[c,e]	Fish	Acid Heavy Metals	Adit, Tailings	Underground	Cu,Zn	14.2[c]	3.1	4200	380	10	(150)	165	4000
Corona	CA-7	22	Fish	[f]	Adit, Tailings	Underground	Hg	14.2	3.3	1100	97	(20)	(38)	(33)	670
Shasta District[h]	CA-8	18	Fish	[f]	Adit, Tailings Waste Dumps	Underground Surface	Ag,Au,Cu Zn,Cd,S	[i]	2.0	8600	790	33	19	63	-
Big Boy	CA-9	-	Minor	Erosion Sediment	Tailings	Underground	Hg			NO DATA AVAILABLE					
Sylvia	CA-10	-	Minor	Sediment	-	Surface Hydraulic	Au			NO DATA AVAILABLE					
Blue Ledge	CA-11	-	Minor	Acid	-	Underground	Cu,Ag,Au Pb			NO DATA AVAILABLE					
Copper Bluff	CA-12	-	[j]	Acid Heavy Metals	Adits	Underground	Cu			NO DATA AVAILABLE					
Greenhorn	CA-13	-	Aesthetics	Acid	-	-	Cu			NO DATA AVAILABLE					
Engle	CA-14	-	Fishing [k]	Acid Heavy Metals	-	Underground	Cu	Small Flow		NO DATA AVAILABLE					
Iron Duke	CA-15	-	Aesthetics	Acid Heavy Metals	-	-	Cu			NO DATA AVAILABLE					
Abbot	CA-16	-	-	Acid Heavy Metals	-	Underground	Hg	[n]		NO DATA AVAILABLE					
Reed	CA-17	-	[l]	Acid	-	-	Hg	[l]		NO DATA AVAILABLE					

(Continued)

TABLE D-4. CALIFORNIA (Continued)

Mine or District	Map Reference	Water Quality Impact		Problem Type	Associated With	Type Mining	Materials Mined	Mine Discharge (l/sec)	pH	Annual Loading (metric tons/yr)					
		Km of Stream	Beneficial Use							Acid As $CaCO_3$	Fe	Cu	Mn	Zn	SO_4
Great Western	CA-18	-	Aesthetics Fishing	Acid	-	-	Hg			NO DATA AVAILABLE					
Big Injun	CA-19	-	-	Erosion Acid-Hg	-	Surface Open Pit	Hg			NO DATA AVAILABLE					
Kellog	CA-20	-	Fishing	Acid Heavy Metals	-	Underground	Hg			NO DATA AVAILABLE					
Dairy Farm	CA-21	-	Fishing	Acid Heavy Metals	-	-	Cu	Small Flow		NO DATA AVAILABLE					
Copper Hill	CA-22	-	-	Acid Heavy Metals	-	-	Cu			NO DATA AVAILABLE					
Newton	CA-23	-	-	Acid Heavy Metals	-	-	Cu	[n]		NO DATA AVAILABLE					
Argonaut	CA-24	-	[m]	Acid Heavy Metals	Tailings	Underground	Au			NO DATA AVAILABLE					
Copperopolis	CA-25	-	Aesthetics Fishing	Acid Heavy Metals	-	-	Cu			NO DATA AVAILABLE					
Mt. Diablo	CA-26	-	[k]	Acid	-	Underground	Hg	[n]		NO DATA AVAILABLE					

[a] Naturally caused. Drainage from adit diverted.
[b] Hg concentration in fish tissue.
[c] Estimated or assumed data.
[d] Geologically reactive area. Many old stream terraces show evidence of $Fe(OH)^3$ cementing below main area.
[e] Heavy metals have caused fish kills d/s from Comanchee Reservoir.
[f] Acid, heavy metals, and silt.
[g] There are twelve significant mines and four smelter sites within the problem area.
[h] Since 1960, there have been 15 fish kills at seven locations with over 59,000 fish reportedly killed, principally in Spring, Squaw, and Backbone Creeks.
[i] Only those streams with pH 6.5 were used considered for pollutant loading.
[j] Depressed aquatic organisms in Trinity River.
[k] Fish are threatened by spring freshets.
[l] Stock watering. Flow dissipates on private land.
[m] Stockwatering, domestic, and fishing.
[n] Variable flow - dry in summer.
[o] Small amount mercury noted.

TABLE D-5. COLORADO

Mine or District	Map Reference	Water Quality Impact		Problem Type	Associated With	Type Mining[a]	Materials Mined	Mine Discharge (l/sec)	pH	Annual Loading (metric tons/yr)					
		km of Stream	Beneficial Use							Acid As $CaCO_3$	Fe	Cu	Mn	Zn	SO_4
Jamestown	CO-1	14	Fish	Acid Metals	Tailings	-	Pb,Au,Ag Fluorspar	10.6	6.6	14.5	1.0	0.1	2	4	(14)
Black Hawk Central City	CO-2	20[b]	[c]	Acid Metals	Tailings Adits[d]	Underground	Au,Ag,Cu Pb,Zn,U	2.0	6.3	1.6	0.2	0.1	0.1	0.1	(2)
Idaho Springs	CO-3	65[b]	Fish Domestic	Acid Metals	Adits Tailings[d]	Underground	Au,Ag	28.0	6.8	4300	390	8	69	43	(4100)
Minnesota, Lion Creek	CO-4	9[b]	Fish Domestic	Acid Metals	Adits Tailings	Underground	Au,Ag	7.0	4.0	91	8.3	0.9	5.6	0.5	(88)
Urad- Henderson	CO-5	8	Fish	Metals	Adits Tailings	Underground	Mo	2.0	7.2	0.2	<0.01	<0.1	0.5	0.1	(.2)
Leadville- St. Kevin	CO-6	110	Fish	Acid Metals	Adits Tailings[d]	Underground	Au,Zn,Pb Ag,Cu,Mn Fe,Bi	348	7.5	3600	330	3	87	480	(3400)
Lake Creek	CO-7	13	Fish	Acid Metals	Adits[d]	Underground	Au,Pb,Ag Zn	238	5.1	360	33	1	7	6	(345)
Kerber Creek	CO-8	43	Fish	Acid Metals	Adits Tailings[d]	Underground	-	2150	-	1700	157	15	100	116	(1690)
Creede	CO-9	18	Fish[a,e]	Metals	Tailings	-	Ag,Pb,Zn Au,Cu	1274	-	100	9.2	4.0	7	40	(96)
Summitville	CO-10	50[f]	Fish	Acid Sediment	Adit Tailings[f]	Underground	Ag,Au,Cu Pb	340	-	28	2.6	0.2	2	0.8	(27)
Montezuma	CO-11	35	Fish	Acid Metals	Adit Tailings	Underground	Pb,Zn,Au	3360	-	610	56	2	8	690	(590)
Breckenridge	CO-12	10	Fish[c]	Acid Metals	Adit Tailings	Underground	Au,Ag,Pb, Zn	42.4	-	2.9	.27	<0.1	2	5	(3)
Crested Butte	CO-13	35	Fish	Acid Metals	Adit Tailings	Underground	-	54	-	105	9.7	0.4	37	24	(101)
Red Mountain Uncompangre	CO-14	50	Fish	Acid Metals	Tailings	-	Cu,Pb,Zn Ag,Au	NO DATA AVAILABLE			3.8	0.2	0.6	0.25	-

[a] Type of mining not known for all mines at each area. Underground mines practiced at all places where adits are reported.

[b] Exact length influenced by CO-2, 3, 4 indeterminable due to comingling of streams. Total length effected by all three areas = 100 km.

[c] Aquatic diversity limited.

[d] Problems also associated with drainage adits.

[e] Fish kill in 1971 due to tailings dam failure.

[f] Area of hydrothermally altered rock much of drainage natural. Natural seeps have concentration as high as Fe = 170 mg/l and Mg 5-7.

TABLE D-6. IDAHO

Mine or District	Map Reference	Water Quality Impact		Problem Type	Associated With	Type Mining	Materials Mined	Mine Discharge (l/sec)	pH	Annual Loading (metric tons/yr)					
		km of Stream	Beneficial Use							Acid As $CaCO_3$	Fe	Cu	Mn	Zn	SO_4
Blackbird	ID-1	50	Fish	Acid Heavy Metals	Adits Tailings	Pits Underground	Co	11.3[a]	4.5	20	2	0.7	(.7)	(.6)	(19)
Stibnite	ID-2	[b]	Fish Aesthetics	Sediment	Tailings	Pits	Sb			NO DATA AVAILABLE					
Bunker Hill [e,g]	ID-3	55	Fish	Acid Heavy Metals	Tailings	Underground	Zn,Pb,Sb	358[a] 176	3.3 2.5	109 205	(10) (19)[a]	2.0 4	(4) 7	480 830	(105) (197)
Bear Valley	ID-4	-	Fish	Sediment	Tailings	Dredge	Ag			NO DATA AVAILABLE					
Big Creek	ID-5	-	-	Sediment	-	-	-			NO DATA AVAILABLE					
Warren	ID-6	-	-	Sediment	Adits	Underground	Au			NO DATA AVAILABLE					
Thompson[h] Creek Project	ID-	-	-	Heavy Metals	Adits	Underground	-	[a]		NO DATA AVAILABLE					
Georgetown Canyon	ID-8	-	-	Sediment	Tailings	-	Phosphate			NO DATA AVAILABLE					
Waterloo[c]	ID-9	-	-	Sediment	Tailings	-	Phosphate			NO DATA AVAILABLE					
Mores Creek	ID-10	-	-	-	-	Dredge	-			NO DATA AVAILABLE					
Jack Waite[f]	ID-11	8	Fish	Heavy Metals	-	Dredge	-			NO DATA AVAILABLE					
Continental[f]	ID-12	20	Fish	Heavy Metals	-	Dredge	-			NO DATA AVAILABLE					
Pearl	ID-13	-	Fish	Arsenic	Tailings	-	As			NO DATA AVAILABLE					
Silver City	ID-14	-	Fish	Mercury [c]	Tailings	-	Au,Ag			NO DATA AVAILABLE					
Red Ledge	ID-15	-	Fish	Heavy Metals	Adits	Underground	Cu			NO DATA AVAILABLE					

[a] Ephemeral discharge.
[b] South Fork Salmon River water quality emproving and fishing is returning.
[c] Near Montpelier, Idaho.
[d] Hg used as an amalgam escaped during active mining.
[e] This mine is only partially inactive.
[f] These mines to be studied by USFS, see text for reference.
[g] Two distinct discharge locations at time of study.
[h] This mine is in the development stage.

TABLE D-7. MISSOURI

Mine or District	Map Reference	Water Quality Impact		Problem Type	Associated With	Type Mining	Materials Mined	Mine Discharge (l/sec)	pH	Annual Loading (metric tons/yr)					
		km of Stream	Beneficial Use							Acid As $CaCO_3$	Fe	Cu	Mn	Zn	SO_4
Mine La Motte	MO-1	6-16	Fish	Heavy Metals	Adits	Underground	Pb	35.0	8.0	76	7.0	.8	13	1	(73)
Flat River-Bonne Terre	MO-2	64	Fish Benthos	Heavy Metals Sediment	Tailings	Underground	Pb	[a]			NO DATA AVAILABLE				
Washington Co Tiff Mining Area [b]	MO-3	39	Fish	Sediment	Tailings	Surface	Barite				NO DATA AVAILABLE				
Tri-State Area [c]	MO-4	21	Fish	Zn	Adits Tailings	Underground	Pb, Zn	[e]	5.9		NO DATA AVAILABLE			217[f]	

[a] No mine discharge water quality data was available.

[b] 20-30 mines.

[c] 30-100 mines.

[d] Zinc concentration toxic to some fish species.

[e] Data not available on all mines.

[f] Total load of zinc from Center Creek, no data on Turkey Creek.

TABLE D-8. MONTANA

Mine or District	Map Reference	Water Quality Impact		Problem Type	Associated With	Type Mining	Materials Mined	Mine Discharge (l/sec)	pH	Annual Loading (metric tons/yr)					
		km of Stream	Beneficial Use							Acid As $CaCO_3$	Fe	Cu	Mn	Zn	SO_4
Hughesville	MT-1	3[a]	-	Acid	Tailings	Underground	-	2.0	2.9	144	13[b]	0.2[b]	7[t]	7[b]	(138)
McClaren [c]	MT-2	3[d]	Fish	Acid	Tailings	Mill	Cu,Au	21	3.7	260	24	5	2	8	510
McClaren[e]	MT-3	3[f]	-	Acid	Adits, Pits	Pits	Au,Ag,Cu	85	2.8	2300	209	118	30	10	3850
Glengary[e]	MT-4	5	-	Acid	Adits, Pits Dump	Underground	Au,Ag,Cu	7.8	2.7	11	97	34	0.9	0.1	82
Comet[c]	MT-5	6	-	Heavy Metals	Tailings	Underground	Pb,Zn,Au, Ag,Cu	3.3	6.6	3	0.2	< 0.1	0.1	0.7	(3)
Crystal	MT-6	26	Fish	Acid	Adits, Pits Tailings	Underground Pits	Ag,Au,Cu Pb,Zn	3.4	-	260	24	7	4	520	(250)
Elkhorn	MT-7	5	Fish	Acid	Adits,Tailings	Underground	Ag,Au,Pb	31	6.5	14	1	0.2	(0.5)	2	106
Heddleston	MT-8	13	Fish	Acid	Adits,Tailings	Underground	Pb,Zn	18.9	4.4	140	13	1	15.5	31	550
Grasshopper Creek	MT-9	24	-	Sediment	Tailings	Placer	Au			NO DATA AVAILABLE					
Sunshine[g]	MT-10	None	-	[h]	-	Underground	Pb,Ba			DISCHARGE DOES NOT REACH STREAM					
Alta	MT-11	10	-	Acid Metals	Adit, Pits Tailings	Underground Pits	Pb,Zn,Cu Ag,Au	0.3	-	17	2	< 0.1	5	3	(16)
Frohner	MT-12	5	-	Acid,As	Adit, Pits	Underground	Pb,Zn,Cu Ag,Au	2.0	3.0	28	3	< 0.1	(1.0)	0.1	(26)
Gold Creek Placer	MT-13	32	-	Sediment	Tailings [i]	Placer	Au			NO DATA AVAILABLE					
Forest Rose	MT-14	-	N/A	TDS,Color	-	Underground	Au,Ag,Pb Zn			NO DATA AVAILABLE					

[a] Galena Creek.
[b] Data from pages 20-24, Reference 518, converted to MT/yr, and sampled 11/28/73.
[c] Mine or mill tailings.
[d] Soda Butte Creek.
[e] Mine area.
[f] Daisy Creek, Stillwater.
[g] Load prospect.
[h] Potential metal problem.
[i] Relocation of stream.
[f] Lowest pH.

TABLE D-9. NEVADA

Mine or District	Map Reference	Water Quality Impact		Problem Type	Associated With	Type Mining	Materials Mined	Mine Discharge (l/sec)	pH	Annual Loading (metric tons/yr)					
		Km of Stream	Beneficial Use							Acid As $CaCO_3$	Fe	Cu	Mn	Zn	SO_4
Jarbridge	NV-1	-	-	Color	-	Underground	Au,Ag	23	6.5	20	2	(0.4)	(0.7)	(0.6)	(19)
Rio Tinto	NV-2	-	Fish	Acid	Tailings	Underground	Cu	0.2	2.2 [a]	300 [a]	8 [a]	1 [a]	(11)	(10)	(290)

[a] Used average of analyses for July-August 1974.

TABLE D-10. NEW HAMPSHIRE

Mine or District	Map Reference	Water Quality Impact		Problem Type	Associated With	Type Mining	Materials Mined	Mine Discharge (l/sec)	pH	Annual Loading (metric tons/yr)					
		Km of Stream	Beneficial Use							Acid As $CaCO_3$	Fe	Cu	Mn	Zn	SO_4
Ore Hill	NH-1	5	Fish	Heavy Metals	Tailings	-	Mica	28.3[a]	7.5	-	2	1	-	23	-

[a] Stream Flow Assumed at 1cfs.

TABLE D-11. NEW YORK

Mine or District	Map Reference	Water Quality Impact		Problem Type	Associated With	Type Mining	Materials Mined	Mine Discharge (l/sec)	pH	Annual Loading (metric tons/yr)					
		Km of Stream	Beneficial Use							Acid As $CaCO_3$	Fe	Cu	Mn	Zn	SO_4
Adirondack	NY-1	None	None	-	-	-	Fe	8.8	6.5 [a]	.57	0.1	(<0.1)	(<0.1	(<0.1)	(0.5)
Stella	NY-2	[c]	[c]	Acid	Tailings	-	Fe	7.0[a]	3.1	870	87	NO DATA AVAILABLE			330

[a] Application has been made for a NPDES permit. Values shown are those permissible under permit.

[b] Estimated or assumed data.

[c] Effects on Elm Creek being studied.

TABLE D-12. NORTH CAROLINA

Mine or District	Map Reference	Water Quality Impact		Problem Type	Associated With	Type Mining	Materials Mined	Mine Discharge (l/sec)	pH	Annual Loading (metric tons/yr)					
		km of Stream	Beneficial Use							Acid As $CaCO_3$	Fe	Cu	Mn	Zn	SO_4
Spruce Pine Pegmatite	NC-1	70	-	Sediment	Tailings [a]	Surface	Feldspar Mica Quartz			NO DATA AVAILABLE					

[a] Many inactive small mines (50 plus) and approximately ten active larger mines. Much of problem caused by active mines.

TABLE D-13. OREGON

Mine or District	Map Reference	Water Quality Impact		Problem Type	Associated With	Type Mining	Materials Mined	Mine Discharge (l/sec)	pH	Annual Loading (metric tons/yr)					
		km of Stream	Beneficial Use							Acid As $CaCO_3$	Fe	Cu	Mn	Zn	SO_4
White King	OR-1	16	Fish	Acid Sediment	Adits, Tailings	Underground	U			NO DATA AVAILABLE					
Blackjack	OR-2	6[b]	-	Acid	-	-	-	1.9	2.8	40.2	4	<0.1	0.3	<0.1	(39)
Couger-Independence	OR-3	6[b]	-	Acid	-	-	Au	14.2[a]	3.5	2100	190	.04	7	.5	(1980)
Silver Peak	OR-4	9[b]	-	Acid	-	-	Ag	0.2	3.2	2.7	0.3	<0.1	<0.1	0.2	(236)
Alameda	OR-5	N/A	-	Acid	Adits	Underground	Au,Cu	6.3		NO DATA AVAILABLE					

[a] Assumed flow rate.

[b] Assumed stream effected until diluted by tributary.

TABLE D-14. TENNESSEE

Mine or District	Map Reference	Water Quality Impact		Problem Type	Associated With	Type Mining	Materials Mined	Mine Discharge (l/sec)	pH	Annual Loading (metric tons/yr)					
		km of Stream	Beneficial Use							Acid As $CaCO_3$	Fe	Cu	Mn	Zn	SO_4
Ball Clay[a]	TN-1	20	-	Sediment	Pits, Waste	Surface	Ball Clay			NO DATA AVAILABLE					
Brown Phosphate [b]	TN-2	5	Fish	Sediment	Pits, Waste	Surface	Phosphate			NO DATA AVAILABLE					
Ducktown	TN-3	35	Fish	Sediment Acid Metals	Tailings[c]	Underground	Cu,Fe,S			NO DATA AVAILABLE					
East Tennessee Zinc	TN-4	-	-	Sediment Metals	Tailings	Underground	Zn			NO DATA AVAILABLE					

[a] Approximately 95 percent of District is still active. Most of problem from active mining.

[b] Approximately 90 percent of District is still active.

[c] Denuded land from sulphorous fumes also causing erosion and sedimentation.

TABLE D-15. TEXAS

Mine or District	Map Reference	Water Quality Impact		Problem Type	Associated With	Type Mining	Materials Mined	Mine Discharge (l/sec)	pH	Annual Loading (metric tons/yr)					
		km of Stream	Beneficial Use							Acid As $CaCO_3$	Fe	Cu	Mn	Zn	SO_4
S.E. Uranium	TX-1	-	-	[a]	Tailings	Surface	U			NO DATA AVAILABLE					
Terlingua	TX-2	-	[b]	Sediment Mercury	Tailings Pits	Surface Underground	Hg			NO DATA AVAILABLE					

[a] Potential hazard not documented.

[b] Much of Mercury in sediments from natural sources.

TABLE D-16. VERMONT

Mine or District	Map Reference	Water Quality Impact		Problem Type	Associated With	Type Mining	Materials Mined	Mine Discharge (l/sec)	pH	Annual Loading (metric tons/yr)					
		km of Stream	Beneficial Use							Acid As $CaCO_3$	Fe	Cu	Mn	Zn	SO_4
Pike Hill	VT-1	3[a]	Fish	Acid Sediment	20% Adits 80% Tailings	Underground	Cu			NO DATA AVAILABLE					
Ely	VT-2	5	Fish	Acid	Tailings	Underground Surface	Cu	28.0		NO DATA AVAILABLE					
Elizabeth	VT-3	6	Fish	Acid Heavy Metals	Adit, Pits, Tailings	Underground Surface	Cu	28.3[b]	3.8	1030	290	1	-	1	-

[a] Assumed-based on distance downstream to confluence with dilluting stream.

[b] Stream below mine.

TABLE D-17. VIRGINIA

Mine or District	Map Reference	Water Quality Impact		Problem Type	Associated With	Type Mining	Materials Mined	Mine Discharge (l/sec)	pH	Annual Loading (metric tons/yr)					
		km of Stream	Beneficial Use							Acid As $CaCO_3$	Fe	Cu	Mn	Zn	SO_4
Contrary Creek	VA-1	15	Fish	Acid	Tailings	Underground	Pyrite	130	4.0	540	50	2	4	11	590
Chestnut Creek[a]	VA-2	8	Fish	Acid	Adits Tailings	pits	Pyrite	28.9 8.9 11.4	3.7 3.2 3.1	265 2900 3500	24 270 320	(5) 0.2 0.2	(10) 14 13	(8) 3 4	20.2 950 1100
Kelly Bank	VA-3	-	-	Sediment	Tailings	-	-			NO DATA AVAILABLE					

[a] Three discharge locations.

TABLE D-18. WASHINGTON

Mine or District	Map Reference	Water Quality Impact		Problem Type	Associated With	Type Mining	Materials Mined	Mine Discharge (l/sec)	pH	Annual Loading (metric tons/yr)					
		km of Stream	Beneficial Use							Acid As $CaCO_3$	Fe	Cu	Mn	Zn	SO_4
Holden	WA-1	14	-	Acid Sediment	Tailings	Underground	Cu,Zn,Au Ag	57	4.5 [a]	58	5 [a]	4 [a]	1 [a]	29 [a]	(56)

[a] EPA 1973o.

TABLE D-19. WISCONSIN

Mine or District	Map Reference	Water Quality Impact		Problem Type	Associated With	Type Mining	Materials Mined	Mine Discharge (l/sec)	pH	Annual Loading (metric tons/yr)					
		km of Stream	Beneficial Use							Acid As $CaCO_3$	Fe	Cu	Mn	Zn	SO_4
S.W. Zinc	WI-1	10	-	Acid Heavy Metals	Tailings	Underground	Zn			NO DATA AVAILABLE					

BEST SELLERS NTIS

FROM NATIONAL TECHNICAL INFORMATION SERVICE

Development of Pre-Mining and Reclamation Plan Rationale for Surface Coal Mines
PB-258 041/SET/PAT 590 p. PC$22.50/MF$7.00

Manual of Respiratory Protection Against Airborne Radioactive Materials
PB-258 052/PAT 147 p. PC$6.00/MF$3.00

Design and Construction of a Residential Solar Heating and Cooling System
PB-237 042/PAT 233 p. PC$8.00/MF$3.00

1976 Energy Fact Book
ADA-029 331/PAT 195 p. PC$12.50/MF$12.50

Impacts of Construction Activities in Wetlands of the United States
PB-256 674/PAT 426 p. PC$11.75/MF$3.00

Standardized Development of Computer Software. Part I: Methods
N76-30-849/PAT 389 p. PC$10.75/MF$3.00

A Methodology for Producing Reliable Software, Volume I.
N76-29-945/PAT 228 p. PC$8.00/MF$3.00

Flow and Gas Sampling Manual
PB-258 080/PAT 102 p. PC$5.50/MF$3.00

Solar Heating and Cooling in Buildings: Methods of Economic Evaluation
COM-75-11070/PAT 48 p. PC$4.00/MF$3.00

Data Base Directions. The Next Steps
PB-258 103/PAT 177 p. PC$7.50/MF$3.00

Comparative Study of Various Text Editors and Formatting Systems
ADA-029 050/PAT 93 p. PC Not Available/MF$3.00

Explaining Energy: A Manual of Non-Style for the Energy Outsider Who Wants In
LBL-4458/PAT 78 p. PC$4.50/MF$3.00

A Survey of State Legislation Relating to Solar Energy
PB-258 235/PAT 166 p. PC$6.75/MF$3.00

Cost Estimating Handbook for Transfer, Shredding and Sanitary Landfilling of Solid Waste
PB-256 444/PAT 85 p. PC$5.00/MF$3.00

Coal Liquefaction Design Practices Manual
PB-257 541/PAT 372 p. PC$10.50/MF$3.00

HOW TO ORDER

When you indicate the method of payment, please note if a purchase order is not accompanied by payment, you will be billed an additional $5.00 *ship and bill* charge. And please include the card expiration date when using American Express.

Normal delivery time takes three to five weeks. It is vital that you order by number or your order will be manually filled, insuring a delay. You can opt for *airmail delivery* for $2.00 North American continent; $3.00 outside North American continent charge per item. Just check the *Airmail Service* box. If you're really pressed for time, call the NTIS Rush Handling Service (703)557-4700. For a $10.00 charge per item, your order will be airmailed within 48 hours. Or, you can pick up your order in the Washington Information Center & Bookstore or at our Springfield Operations Center within 24 hours for a $6.00 per item charge.

You may also place your order by telephone or if you have an NTIS Deposit Account or an American Express card order through TELEX. The order desk number is (703) 557-4650 and the TELEX number is 89-9405.

Thank you for your interest in NTIS. We appreciate your order.

METHOD OF PAYMENT

☐ Charge my NTIS deposit account no. ____________
☐ Purchase order no. ____________
☐ Check enclosed for $____________
☐ Bill me. Add $5.00 per order and sign below. (Not available outside North American continent.)
☐ Charge to my American Express Card account number

☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

Card expiration date____________
Signature____________
☐ Airmail Services requested

NAME____________
ADDRESS____________
CITY, STATE, ZIP____________

Item Number	Quantity		Unit Price*	Total Price°
	Paper Copy (PC)	Microfiche (MF)		
			Sub Total	
			Additional Charge	
			Enter Grand Total	

All prices subject to change. The prices above are accurate as of 4/77

Foreign Prices on Request.

Clip and mail to:

NTIS
National Technical Information Service
U.S. DEPARTMENT OF COMMERCE
Springfield, Va. 22161
(703) 557-4650 TELEX 89-9405